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Monterey, California

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Defence of Surface Ships Against
Anti Ship Missiles

by

Ramesh Kumar

September, 1990

Thesis Advisor: Edmund. A. Milne

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This thesis discusses the Anti-Ship Missile problem and explores the various options available for countering the Anti-Ship Missile. Special emphasis has been given to the chaff solution for defeating the Anti-Ship Misile. A program has been written to enable the testing of the effectiveness of the medium range and close range chaff deployed in conjunction with various conditions of wind and various ship's courses. The program can be used to determine the best solution for deploying the medium range chaff given the known parameters such as detection ranges and probable wind conditions.

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Defence of Surface Ships Against Anti Ship Missiles

by

Ramesh Kumar
Lieutenant Commander, Indian Navy
B.Sc., Jawahar Lal Nehru University

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING
(Electronic Warfare)

from the

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September 1990

Joseph Sternberg, Chairman
Electronic Warfare Academic Group

ABSTRACT

This thesis discusses the Anti-Ship Missile problem and explores the various options available for countering the Anti-Ship Missile. Special emphasis has been given to the chaff solution for defeating the Anti-Ship Missile. A program has been written to enable the testing of the effectiveness of the medium range and close range chaff deployed in conjunction with various conditions of wind and various ship's courses. The program can be used to determine the best solution for deploying the medium range chaff given the known parameters such as detection ranges and probable wind conditions.

The program was run with medium range chaff deployed in the default position and the wind's course was varied through 180 degrees. For each of the courses of the wind 3 wind speeds were tried. The ship's course was also varied through 360 degrees for each of the winds courses in 45 degree steps. The seduction chaff was automatically deployed by the program.

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I. INTRODUCTION

A. AIM

The aim of this thesis is to discuss the problem of anti-ship missile defence and to simulate a missile chaff encounter using a Fortran program. The program aims to simulate a missile launched at a ship that is capable of keeping a set of four medium range chaff clouds in place for prolonged durations, renewed every two minutes. The ship launches a new set of medium range chaff clouds every two minutes. The ship is fitted with the following sensors -

- ESM equipment
- A special radar for detecting anti ship missiles
- Visual lookouts
- IRST equipment

B. THE THREAT

It has long been known that intense or well placed anti aircraft fire can deter a pilot and cause him to miss a target. Thus systems that in reality kill very few aircraft can still protect ships against manned aircraft. Unmanned vehicles however are devoid of human caution and this type of defence will not succeed unless it is capable of causing a direct hit. As a result the advent of even the crudest anti ship missiles drastically changed the problem of defending surface ships.

The advent of the anti-ship missile has increased the vulnerability of the warship as no other naval weapon has done before (REF 2). This kind of missile can be launched from OTH (over-the-horizon) distances, at sea skimming altitudes (with a radio altimeter to enable them to fly just above the top of waves) and have targeting electronics by which they can counter at least some of the countermeasures applied by the ship. In addition to the sea-skimming altitudes, their high transonic speed makes early detection virtually impossible which translates into a very short response time for the appropriate countermeasure. The response time would be further reduced by the development of the future anti-ship missiles with maneuvering capability at supersonic speeds. The threat would be even worse if a number of these missiles are launched from different platforms (coordinated attack) simultaneously to saturate the air defenses of the target ship. It should be kept in mind that even fractions of seconds are important when an attacking missile is only seconds away from the impact.

Anti-Ship missiles fly at 3 to 5 meters above the surface of the sea. According to some analysts the Soviet missiles fly at higher altitudes. They operate at speeds (as yet) of .7 to .95 mach. Some of the ASM's in existence are capable of locking on to the radar emissions of a ship or other platform. Most modern missiles have anti-jam capabilities and either shut off their seekers and continue on the previous path or lock on to the jammer (HOJ) if jammed. Some of the more modern missiles are capable of locking on to the IR signature of a ship making them even more dangerous. Many of the intelligent missiles are capable of differentiating between the chaff and the ship by using pulse doppler radars in their seekers. According to some reports the Harpoon is now being updated to be capable of turning around and searching for the ship again if it has been decoyed by a

chaff cloud and has not hit anything. Thus we are talking of an intelligent and difficult adversary when we deal with ASM's.

C. THE DETECTION PROBLEM

The most difficult part of the problem of countering the ASM is the detection. Most ASM's fly at low altitudes and have small radar crosssection. They usually pop up over the horizon at 10 to 15 nm which translates into a reaction time of 60 to 90 sec at 1 Mach missile speed. Radar is so far the most common method of trying to detect the ASM. Some of the more modern radars like the US Navy's Spy-1 radar in conjunction with AN/UYK-7 computer system are supposed to be capable of countering almost any kind of air or missile threat.

The faster the threat, and closer it is the more difficult it is to defeat the Anti Ship Missile with conventional radars (REF 1). This is because they look at a target once in every sweep. Even if this time is of the order of one second the missile may have travelled about 330 yds in this time. This is where electronically scanned radars provide a distinct advantage. They can look all round until the threat is detected and then concentrate on the missile once it has been detected. Also a single radar can track many targets simultaneously. After a target is detected the radar can swing its beam periodically to maintain track without waiting to sweep through the rest of the scanning program. The shift from one target to the other is better for them than conventional radar.

Another difficulty is the multipath problem experienced by radars trying to detect sea skimming targets. This problem could be overcome by electro optic methods and by means of laser radars which due to their narrow beams are not subject to this problem.

But as yet most missile detection radars still operate in the C and X band or higher RF bands. This is because better range is obtained by C and X band radars.

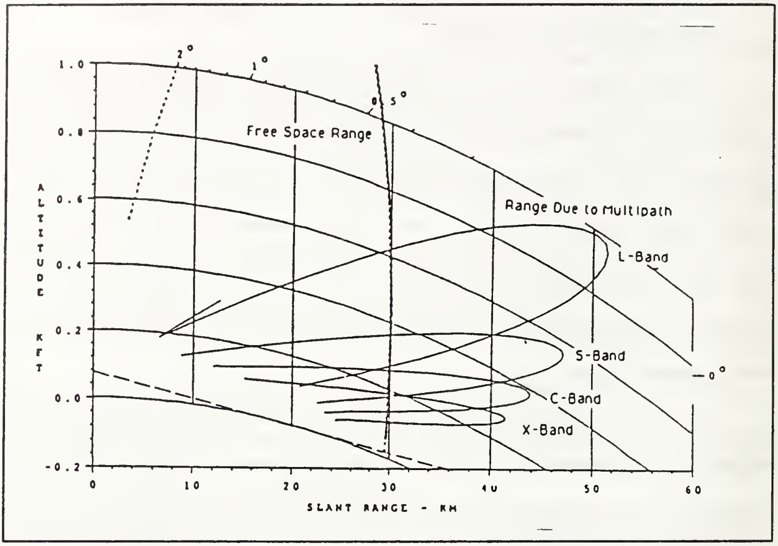


Fig 1 High RF bands are needed to detect low altitude(sea skimmer) low radar cross section targets.(REF 3)

However, radar can act as a beacon for some ASM's and thus cannot be relied upon alone as it may have to be shut down in case the missile locks on to the radar emissions. The other method of detecting the ASM is the ESM on board the ship. Especially using the ducting conditions prevalent at the time and the forward scatter of the missile radar, it could be detected at fairly long ranges. Although most sea skimming missiles do not go active until they are fairly close to the target they do have to operate their radar altimeters all the time. A part of this signal is reflected by the waves in the forward direction and could be picked up by a ships ESM systems if they are sensitive enough. By using the ducting phenomenon that are common enough, though not always reliable, this forward

scatter could be detected early enough. This opens up the possibility of either jamming the altimeter frequency or deploying other defenses . A missile not using the altimeter continuously would have to operate at higher altitudes.

Thus, the use of surface ducts for both one's own radars and to detect the missile radar and its altimeter are distinct possibilities because though surface ducts often do not extend to the ships mast they may be high enough to include the sea skimming missiles.

However, if the missile uses passive HOJ or locks on to the IR signature of the ship it would not be detected by conventional ESM. Also the use of spread spectrum techniques in the missile radars makes them much harder to detect by ESM. The problem of stealth used by some missiles today and by future missiles is also overcome by looking for them in the IR region due to that fact that they cannot reduce their IR signature especially if they go to higher operating speeds. Thus one alternative that seems to offer significant advantages is the advent of IR detection systems (IRST'S) for example the US/Canada venture AN/SAR-8 and the French system Vampir (REF 1). The French system Vampir is claimed to have detected the Exocet far beyond the horizon. In fact the French companies (especially SAT) have in the recent past come up with several systems dedicated to detecting the plume of an ASM. The Vampir is supposedly capable of detecting the ASMs at 12 km or more. Although this data by itself cannot be used for fire control it can be used to trigger decoys and commence ECM. It would also give the other systems time to slew on to the given direction and to provide them ample time for preparation.

Providing defence has become increasingly difficult as the quality of anti-ship missiles has become better. Future sea skimmers are likely to become supersonic. The purpose of the terminal pop up and dive is to make the fire control solution difficult.

Future missiles are also likely to use stealth technology to reduce the RCS and thus reduce the reaction time. The missiles could also have various ECCM techniques incorporated so that any ECM may be rendered ineffective.

1. EQUIPMENT CONSIDERATION

a. RADAR

The aim in consideration of radar is to lay down the requirements for a radar that can take advantages of the anomalous propagation conditions that are prevalent over the ocean and is suitable for Anti Missile Defence. The height and the strength of the trapping layer are important factors in the occurrence of a surface based duct. As the duct height increases the minimum frequency trapped decreases. Observational data indicate that the normal duct heights lie between 10 m and 20 m. An approximate expression for the minimum frequency trapped is given below.

This gives a frequency range from 4.025 to 11.38 Ghz for the minimum frequency trapped. The height at which the radar gives the best performance would be at the top of the duct. So this is the ideal position to place the radar antenna(REF 4). Thus if the duct height position could be accurately estimated and the antenna height could be varied to be at this height extensive ranges could be obtained.

Minimum frequency trapped

$$\boxed{f_{min}=3.6033*10^{11}*d^{-3/2}}$$

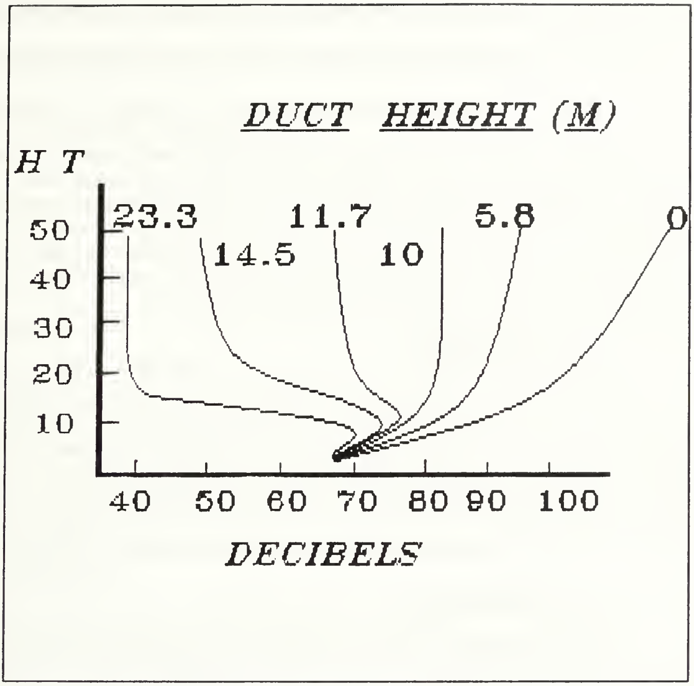


Figure 2 DUCT HEIGHT VS GAIN.(REF 4)

The above figure is adopted from figures demonstrating surface to surface detection phenomena for the Harpoon missile (REF 4). It is interesting to note that the gain is high when the antenna is at the height of the duct. This would significantly improve the S/N ratio and thus the chances of detection. The approximate evaporation duct height can be calculated by using the known methods of calculation with a fair amount of accuracy. Hence for the purposes of this thesis a radar is assumed for which the range of detection of the missile is distributed between RHR (radar horizon range) for a missile height of 3 - 5 m and a duct height that has been given specific values for each month of the year(between 40

and 55 feet). This is only for the purposes of the program. In real life the range would be determined by the actual radar which would be suitably placed in the duct. The power output and other parameters of the radar are not being discussed except to say that the radar would be a pulse doppler radar with a high prf and prf stagger capability. The pulse doppler is more capable of reducing clutter and the prf stagger is required to ensure there are no range ambiguities. The high prf ensures a high data rate that is required for a missile problem.

b. IRST EQUIPMENT

It is important to understand that the IRST type of equipment offers significant advantages in detection of a missile especially if the visibility is good and the contrast is significant. Typically, ranges obtained would be of the order of about 10 - 15 nm. The French system Vampir offers a range of at least 12 Km for the detection of a sea skimmer.

c. ESM EQUIPMENT

The ESM equipment should be capable of detecting transmissions in the range in which the modern sea skimming missiles operate. The ESM equipment should be able to identify the transmissions from the missile or the Launch Platform almost instantaneously. Thus it should cover the frequency range from 6 Ghz to 30 Ghz and have a comprehensive radar threat library associated with it.

d. VISUAL LOOKOUTS

The visual lookouts would have to be trained in detecting small low flying objects in adverse weather conditions and in conditions of stress. The average human being can sustain a high efficiency for durations of not greater than about an hour and hence in addition to being briefed about the threat the lookouts should be rotated every

hour at least. The performance of the lookouts can be assumed to be distributed uniformly between the visibility range and a range 5 nm less than that.

D. COUNTERING THE MISSILES

Assuming that the missile has been detected the next question is to how to engage it and to employ countermeasures against it. The current choices for engaging include guns and missiles; lasers and directed particle beams are likely to be the weapons of the next century. There is a breakup in the ranges of engagement of missiles and guns because missiles inherently need time to accelerate to a speed at which their control surfaces become effective. Rounds fired from guns do not have this problem. However, the fact that these rounds take some time to reach their targets and they cannot be repositioned during their flight causes errors in the fire control solution which become unacceptable beyond 4000-6000 yds.

To understand how to defeat the ASM it is necessary to look at the phases of a missile attack. The attacking cycle of the enemy platform still depends on first detecting the target ship. In the earliest stages preceding a surface engagement neither side knows the precise location and composition of the opposing forces. Each side seeks to locate and identify the other side's forces. This is the surveillance phase. Radar is one type of sensor used for surveillance, though by no means the only one. The surveillance radars may in some cases be land based but will more often be aboard satellites, aircraft or surface ships. The surveillance platforms may or may not have an attack capability.

After the opposing fleet has been found and its approximate location determined by surveillance radars or other means, the next stage is the deployment of attacking launch platforms and selection of specific targets for missiles or gun fire. This is called the

targeting phase. The radars employed in targeting are usually aboard the ships or aircraft that launch the Anti-Ship Missiles.

The third phase, the mid course guidance phase, occurs after the missile launch. The midcourse portion of the guidance phase may or may not use radar sensors. Some anti-ship missiles use inertial guidance until they approach the target, then turn on their radar and acquire the first target that meets the designation criteria.

The final phase is the terminal guidance phase, in which the missile radar is actively tracking the target ship, and attempts to home on the radar echo. For a radar guided missile to be successful it is necessary for each of the stages to be successfully negotiated.

The Fortran program (Countering an Anti-Ship Missile Using Medium Range and Seduction Chaff) in this thesis looks at the distraction of the Anti-Ship Missile when it opens its homing head and its seduction if it still manages to lock on to the ship. The seduction chaff round is placed by the program in the position that is most suitable. However the medium range chaff round can be placed by the user at any position. Based on the results of these trials the best position to launch the medium range chaff round can be determined. This is discussed in Chapter II.

In order to effectively engage the missile, detection and tracking of the missile has to be maintained by means of active and the passive sensors. Active detection includes radar and laser radar (REF 6). Passive detection includes detecting the missiles active radar, electronics, acoustic, thermal IR emissions and other power sources from the target. Passive detection ranges are much greater than the active detection ranges due to the one way propagation of the electromagnetic wave in the propagation medium. After initial detection and identification is gained, a targeting solution is obtained by employing specific location of the target. Once the targeting solution is obtained the anti-missile weapons can

be launched. Active detection and targeting sensors are in turn subjected to passive detection by the defence providing alert and warning. The best solution is of course to destroy the missile launch platform. However, this is not always possible.

1. HARD KILL OPTIONS

a. THE MISSILE SOLUTION

The anti-missile missiles can be either semiactively guided or command guided. The Standard missile (except in the Aegis and new threat upgrade ships) and the Sea Sparrow employ semi active guidance (REF 1). However, the Standard/SM2 missile used in conjunction with SPY_1 radar in Aegis equipped ships, the French Naval Crotale, and the Seawolf employ command guidance. The command guidance system could put the missile into a basket close to the Anti-Ship Missile and then it could use semi active guidance. The SPY_1 used on the Aegis ships defines many such baskets because it is electronically scanned and slave illuminators are switched on for terminal guidance. This approach is better in some cases because the missile cannot generate sufficient power on its own for guidance at a distance. The missile could also home on to the IR glint of the skin of the Anti Ship Missile. The recent defensive missiles with the advantages of VLS (Vertical Launch System), multiple engagement capacity, multiple trackers LLLTV, IR, radar (with independent tracking bands) and hypersonic velocities, can respond to an attacker almost instantaneously.

The US Navy/Raytheon Sea Sparrow is among the early generations of shipborne air defense weapons (REF 8). The current missile in service is the RIM-7M with vertical launching system, monopulse seeker, a proved autopilot, a powerful motor and warhead.

The advantage of the vertical launcher (VL) over the trainable launcher is the amount of valuable space that can be saved and furthermore VL offers a rapid reaction time, solves the reloading problem, and has all around engagement capacity without being interrupted by the ship's superstructure. An enhanced version RIM-7P has been developed with dramatic changes.

The UK Seawolf is another powerful, fast reaction, all weather anti-missile system, used by the British Navy as a point defence weapon, filling the gap between the Sea Dart MR SAM system and CIWSs. Two new versions VL (Vertical Launch) Seawolf and Lightweight Seawolf now have better capability than the original GWS25 system with six barrel trainable launcher. It employs the Marconi 805SW fire control system which features two independent differential tracking radars (I band and millimeter wave), with both antennas comounted. The I band is used for high angle or long range targets while the millimeter wave is used for close-in and low altitude targets. The hand over of the missile is automatic. This gives full blind fire, as well as anti-sea-skimmer capability and good resistance to jamming. Seawolf XL's FCS has I band frequency agile monopulse radar and an IR tracking device to utilize in the case of radar-silent conditions. This is a new version being promoted by Marconi and BAe.

The Thomson-CFS Crotale EDIR (Ecartometery Differentialle Infra Rouge) version is in service in the French Navy. The guidance system follows the multi sensor principle, in which both the J band tracking radar and the thermal imaging tracker provide the computer with the positions of the target and the missile. The new version that will use the VT-1 hypervelocity missile (Mach 3.5) is under development.

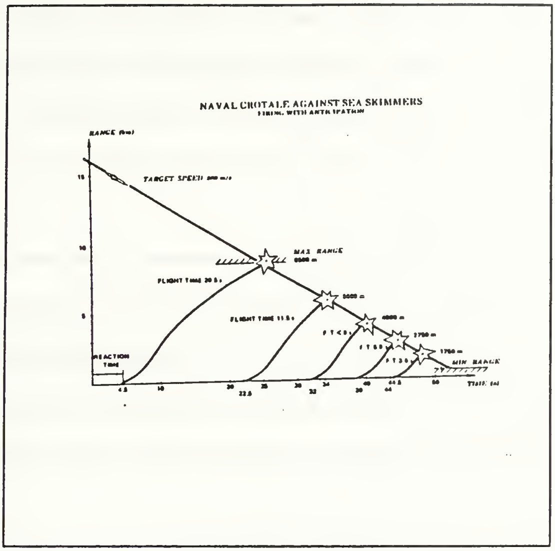


Figure 3 Naval Crotale can effectively counter an ASM.(REF 7).

Israel's Barak 1 is in service in the Israel Navy. The system can have up to 32 missiles stored in vertical launch canisters arranged in packages of eight. The command to line-of-sight guidance is provided by two independent fire control systems with a dual frequency radar (I and K band). The weight of the warhead is 22 kg. incorporating tungsten pellets that maintains absolute destruction of any attacking missile passing within the intercept radius of the laser-diode proximity fuze.

b. GUNS

Medium-calibre guns, with an improved fire rate, accuracy and ammunition, can be used effectively against current ASMs including sea-skimmers. They may also be

considered as an alternative to the CIWS's (close in weapon systems) with their long range advantage. The overall effectiveness of the these guns is highly increased by the employment of pre-fragmented projectiles containing 1000 to 1500 small dense metal pellets or cubes which gives a lethal radius of 8-10 m for a 100 mm projectile. The effectiveness of the projectiles is even more increased by using proximity fuzes that can detect sea-skimmers within several meters.

CCS (course corrected shells) are another aspect in the future development of ASM defence. When the FCS (fire control system) of the ship detects an alteration in the course of the incoming missile it re-calculates the predicted hitting point for each of the in-flight projectiles and sends course correction information by means of an RF link. Thrusters on the projectile are used to produce the desired course change, up to about 10-15 degrees.

The same approach that is used for the medium calibre guns can also be used for the small calibre guns, which enables 40 mm ammunition to be fitted with proximity fuzes.

All of the CIWS are based on high rate of fire as being the innermost zone of the ship's ASM defense system; using the high kinetic energy of the ammunition to defeat the warhead of the missile.

A few of the currently used systems of both categories are listed below :

1) OTO Melara- Of the medium calibre guns the Super Rapid version of OTO Melara has already entered service in the Italian Navy. It is capable of firing more than 120 rounds/min.

2) Bofors Sea Trinity- This is an example of the small calibre guns. Bofors has developed the pre-fragmented, programmable proximity-fused high velocity 3P (PFPPX-HV) round for its Trinity gun system. It contains Tungsten pellets and

FES POSITION DESCRIPTION
for
Technical Information Specialist
Cataloging and Metadata
GS-1412, Grade 11
Dudley Knox Library, Naval Postgraduate School

I. INTRODUCTION

This position is responsible for performing original cataloging and related duties necessary to create metadata for discovery of and access to information resources in all formats for inclusion in Dudley Knox library print, digital and archival collections. The incumbent is responsible for performing original and copy cataloging, applying indexing terms, developing metadata schemas, creating and managing authority records for unique NPS entities and materials and for assuring that records interface with OCLC and other digital registries. The incumbent is expected to provide expertise specific to cataloging and maintaining library bibliographic and archival databases and for staying abreast of emerging trends and issues impacting cataloging and metadata processes, guidelines, and standards as well as the automated tools to manage them in academic libraries.
A SECRET security clearance is required.

II. MAJOR DUTIES AND RESPONSIBILITIES

1. Cataloging and Metadata (60%)

The incumbent is responsible for providing original and descriptive cataloging, subject analysis and classification, assigning subject headings, creating authority records, documenting processes and procedures necessary to ensure access to library information resources and collections in all formats. This position is responsible for interpreting existing metadata and cataloging standards and guidelines, creating crosswalks between systems, and for staying abreast of emerging issues impacting traditional cataloging and metadata management of digital and print resources in academic libraries. The incumbent is expected to utilize automated tools and resources to capture and import bibliographic data from OCLC, publisher databases, and other sources and to add specific content to that data in compliance with recognized cataloging standards and guidelines. The incumbent will be responsible for following and documenting cataloging and metadata decisions and

processes unique to the NPS environment and for gathering and reporting cataloging metrics in support of library initiatives. Familiarity with open source, SIRSI-Dynix Unicorn or Symphony (or similar) integrated library system software modules, digital archival and other software/systems for cataloging, serials control and acquisitions is required. Knowledge and ability to interpret and apply appropriate metadata standards such as OCLC, AACR2, MARC, XML, OAI-PMH, SCORM, VRA, Dublin Core and ADL Registry guidelines, protocols and structures is required. The incumbent is expected to perform quality assurance testing in support of cataloging, acquisitions, serials control and authority functions during hardware/software upgrades.

2. Authority Controls (30%)

The incumbent is responsible for authority control in the library and as such creates, manages, and shares authority controls for all cataloged resources. The incumbent will create and maintain local authority control documentation and propose changes to existing processes and procedures. The incumbent is required to stay abreast of issues and technologies impacting authority control in academic libraries and to surface those issues for discussion by senior management when decisions are required. The incumbent maintains the name, title, subject and series authority files consistent with established library standards and local implementation of those standards in the DKL online catalog. The incumbent is expected to utilize automated tools and resources from the Library of Congress, OCLC, DTIC and publisher/alternative sites as may be required to achieve uniformity in the assignment of subject headings and authority records when cataloging library resources. Knowledge of and ability to apply OCLC, LCSH, RDA and FRBR, SCORM, and OAI-PMH protocols and interpretations when creating authority records is required.

3. Quality Assurance and Accountability (10%)

The incumbent is expected to maintain a high quality of assurance for all catalog, metadata and authority records incorporated into the library online catalog and/or provided to utilities such as OCLC. Basic knowledge of quality assurance processes along with documented procedures for checking accuracy of original cataloging and authority work is required. The incumbent is required to track and report workflow outputs in support of library metrics. The

incumbent is expected to stay abreast of quality assurance and accountability initiatives affecting cataloging and metadata management as well as authority control in academic libraries. The incumbent is expected to provide expertise and stay informed regarding changes to existing national and international standards and guidelines and to inform supervisor when proposed changes may impact library collections, resources or processes.

FACTOR 1. KNOWLEDGE REQUIRED BY THE POSITION.

- Knowledge of the organizational structure and programs of the Naval Postgraduate School, the Department of the Navy and the Department of Defense
- Knowledge of the library tools, resources, theories and techniques involving cataloging library resources, capturing and managing metadata and managing authority controls
- Knowledge of OCLC, MARC and non-MARC formats, LCSH, METS, OAI-PMH, SCORM, Dublin Core, VRA, CONSER and ONIX standards and protocols impacting guidelines and structures for cataloging, metadata, digital archives, and managing library bibliographic data
- Ability to understand, interpret and utilize automated tools necessary for cataloging and managing library metadata and authority controls
- Ability to understand and utilize modules of an automated ILS (such as SIRSI Dynix Unicorn or Symphony) or archival/digital software to catalog library print and digital resources
- Ability to work effectively as a team member
- Ability to adapt to rapidly changing technologies and environments in a academic library
- Ability to work collaboratively with other library staff to identify and resolve issues impacting delivery of library content in a cohesive manner utilizing all automated formats
- Ability to work with emerging technologies and evolving processes which touch on cataloging, metadata management and authority control
- Ability to be accountable for work products

FACTOR 2. SUPERVISORY CONTROLS

This position reports to the Supervisory Librarian responsible

for managing Library Systems and Metadata Services. Work is assigned by the supervisor; priority is placed on timely and accurate completion of original cataloging, copy cataloging, metadata creation/management, and authority control within the library. The incumbent is responsible for controlling the output of workload for these functions so that no backlog of critical items occurs. The incumbent is expected to work independently within established guidelines and to surface complex issues requiring primary decisions to the supervisor. Work is evaluated for accuracy, completeness and conformance to established guidelines and principles of academic cataloging, metadata management and authority control.

FACTOR 3. GUIDELINES.

Guidelines are online and written manuals governing standard cataloging, metadata, and authority control regulations and rules; (AACR2, LCSH, COSATI, CONSER, OCLC, RDA, FRBR, METS, SCORM, VRA, OAI-PMH and DTIC) are some of the examples that are used. The incumbent works under these guidelines, using experience, judgment and knowledge to interpret and apply those guidelines. Some of these guidelines are continuously being revised and others are under development; the incumbent is expected to stay abreast of these changes and to inform library management when changes to existing processes and procedures are recommended or required based on changes instituted by these guidelines.

FACTOR 4. COMPLEXITY

Duties involve in-depth and specialized knowledge of cataloging, metadata management and authority control processes in order to interpret and apply complex and detailed guidelines and regulatory principles. These guidelines and regulations are continuously evolving and most are automated; therefore, the incumbent is required to practice vigilance in monitoring and reviewing these guidelines and regulations to insure application within the library and compliance when merited by library supervisor and management.

FACTOR 5. SCOPE AND EFFECT.

The purpose of this work is to insure library materials requiring original cataloging, description of metadata, copy cataloging and authority control are consistently and accurately processed in a timely manner to support access by NPS clientele (faculty, students, researchers and staff) on campus and by authorized personnel at remote locations. The incumbent

is expected to contribute unique Naval Postgraduate School records for inclusion in a shared national database (OCLC) and for insuring these records conform to the high standards for original cataloging required by OCLC. Completion of original cataloging workload affects operations within the library's Library Systems and Metadata Services unit to prevent workflow backlogs and to insure library materials are moving through the processing steps necessary to insure access by library users. Accuracy of authority control records in the library's ILS affect efficient search ability of the library catalog by all users.

FACTOR 6. PERSONAL CONTACTS.

Contacts are with co-workers in the library and with library staff at other similar academic institutions through on-line participation in various forums and Listservs related to cataloging, metadata management, and authority control processes in academic library settings. Contacts may also be with personnel at OCLC as well as with vendors for the purpose of interpreting, configuring, transferring and verifying cataloging records, metadata and authority control records.

FACTOR 7. PURPOSE OF CONTACTS

Contracts with co-workers in the library are made to coordinate the completion of original cataloging workload, the creation and maintenance of authority control records and the creation and management of metadata for print and digital resources generated and managed in Naval Postgraduate School collections. Contacts may also be with OCLC, vendors, and representatives of other libraries responsible for interpreting, creating, managing or transferring cataloging, metadata or authority control information

FACTOR 8. PHYSICAL DEMANDS

Office type work is primarily sedentary at a computer workstation but may involve some standing, bending, stooping, stretching, reaching and lifting of moderately heavy items such as books, journals, equipment and supplies.

FACTOR 9. WORK ENVIRONMENT

Work is performed in an office/research library setting.

has a lethal radius of 3 m. The Sea Trinity has high single shot kill probability at the ranges well above the current CIWS. It can employ different on-mount sensors for tracking such as a sophisticated tracking radar, TV tracking camera and a laser range finder.

3) Bareda- The Swedish Bareda is another example of small calibre guns. It has a dual kill mode that uses armour piercing armour automatically when the distance falls below 100 m.

4) US Phalanx- This is another of these systems. It is currently upgraded for defence against pop up missiles.

5) Goalkeeper- The Goalkeeper is another CIWS, which employs GE Sea Vulcan 30 mm seven-barrelled Gatling guns and is capable of firing at the rate of 4200 rounds per minute. It has an on-mount 2-D, I band search radar and a tracking radar using dual frequency. In addition, the IRSCAN IR passive surveillance and tracking system can also be combined with the Goalkeeper.

6) Seagaurd- The Seaguard CIWS is currently in service in Turkish Navy. It employs a search radar, a Ku band tracking radar, a FLIR and a laser range finder with Sea Zenith quadruple guns which gives the ship a full horizon coverage against the missile threat, from sea level to zenith.

2. THE SOFT KILL OPTIONS

Since the miniaturization technologies such as very high speed integrated circuits have developed greatly during the last decade, the effectiveness of the Soft Kill is also improved in ASM defense. The majority of the ASMs use active radar with an IR sensor as back-up which increases the importance of the chaff and infrared flares for ASM defense. Both the chaff and the flare are heavily dependent on the sea and weather

conditions along with the direction of the incoming threat and the ship's course. In order to be completely effective, chaff and flares must also be linked with ESM systems which will provide targeting information besides detection. Such systems can get this information by means of radar warning receivers but may include radar jammers that would act as a beacon for the ASM after launch.

Chaff, flares, jammers, active and passive decoys are the most common of the soft kill systems used. Of these active and passive decoys (other than chaff) are discussed here and chaff which is the thrust of this thesis is discussed in the next chapter.

a. Passive Decoys

Passive decoys are basically inflatable, highly reflective structures with designed shapes and materials that can simulate the ship's signature by reflecting back the threat radar signals. Thus, they can be used in decoying radar homing sea-skimmer missiles.

The Replica is a passive ASM decoy system that is in service in the US and UK Navies(REF 10). The decoy configuration consists of two life-raft size watertight packages that begin inflating following release from inclined ramps. Replica is an effective radar decoy both because of its octahedral shape and corner reflecting design, and its construction of silver coated mesh. Another advantage is that it can confuse radar homing heads even if the missile contains chaff discrimination circuits. It can operate both in the distraction/false target role or in the seduction role, given enough time. Operation is fully automatic and the elements can be repositioned with remote control. By adding an RF link delayed-action mechanism, the number of these passive decoys can be used to generate 'Phantom' fleets as a part of deception plan.

b. *Active Decoys*

Considering only Soft Kill, the most effective way of countering ASMs would be the maneuverable active off-board decoy which is capable of receiving, amplifying, and retransmitting the missile's radar signal. Since the aim is to decoy the oncoming missile with a radar signature that is more powerful than the ship's signature, the EW payload of these active decoys is capable of generating this powerful spurious signal. Besides the maneuverable ones some other models use parachutes to descend slowly or are towed behind the ship. But the descent with parachute is also dependent on the wind conditions as chaff is, and towing behind the ship would constrain the ship's maneuvers. Since the active decoys are off-board self-activated systems, the ship is put at less risk.

Currently Australian Winnin is one of these active decoys. The 100 pound, six foot rocket typically would be launched almost vertically and move away from the ship in a preprogrammed trajectory that would ensure that the missile would pass under the rocket. It has high maneuver capability, the trajectory is totally under control by the available thruster and a digital autopilot. The system can be updated in flight and can operate in very rough weather conditions. The rocket can also be launched from the MK 26 chaff launcher which makes it available for small size boats. The EW payload of the rocket, using travelling wave tube and extensive electronics miniaturization, is not threat specific and not easily saturated, meaning that it can defend against a saturated attack.

UK Siren is another intelligent active decoy, 1.8 m long with a weight of 28 kg. Upon launch it accelerates to a position 400-500 m away from the ship,

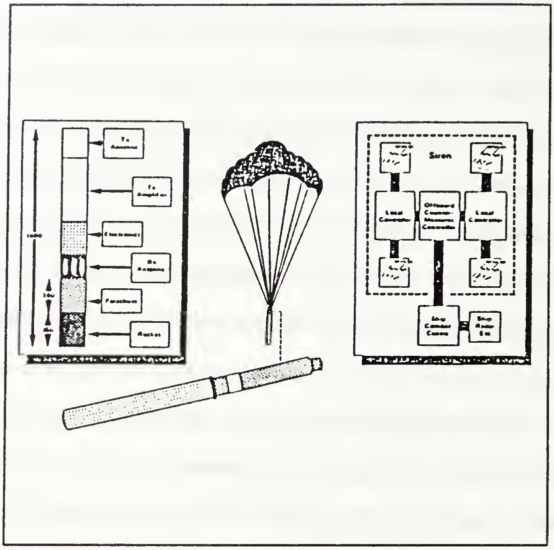


Figure 4 The Siren Decoy descends by parachute while its onboard jammer operates in the seduction mode on the same frequency as the incoming missile. (REF 2)

then a specially designed parachute opens and drifts the rocket and when its radar receiver detects an oncoming missile the on board jammer begins operating in seduction mode on the same frequency as the missile. It includes a low g rocket, parachute, transmitter, receiver and antennas, control electronics and a battery source. After launch it switches to internal power and can be coupled to sensors on board, such as a radar warning receiver, to allow fully automatic, semi-automatic and manual decoy activation. Its launchers are also capable of firing chaff and flare rounds. The system's off-board controller not only provides the required interface to other ship defense systems, but also uses internal micro-processors to determine the most appropriate countermeasures, launchers, and deployment position. It can be configured as a stand-alone system.

French LAD is an active decoy similar to the Siren system. It can be launched within 8 sec after detection, uses a parachute descent while producing spurious ship return and decoying the missile away. The wide band I/J-band electronic payload allows processing of all known present and also future types of electromagnetic seekers. Its dimensions are 1.76m by 127mm and weight is about 27kg.

Italian TOAD is a towed off-board active decoy which has a radar detector, a signal processor, and an amplifier, with receiver and transmitter antennas.

As a result, active off-board decoys enhance the ship survivability against ASMs. As the ASMs become more sophisticated, the active decoys must also be improved in capability and size. Currently the maneuverable off-board decoy presents the most effective response. But these can be very expensive. And for the future the active decoy may be replaced with an unmanned air vehicle which would provide constant wide area coverage and instantaneous response.

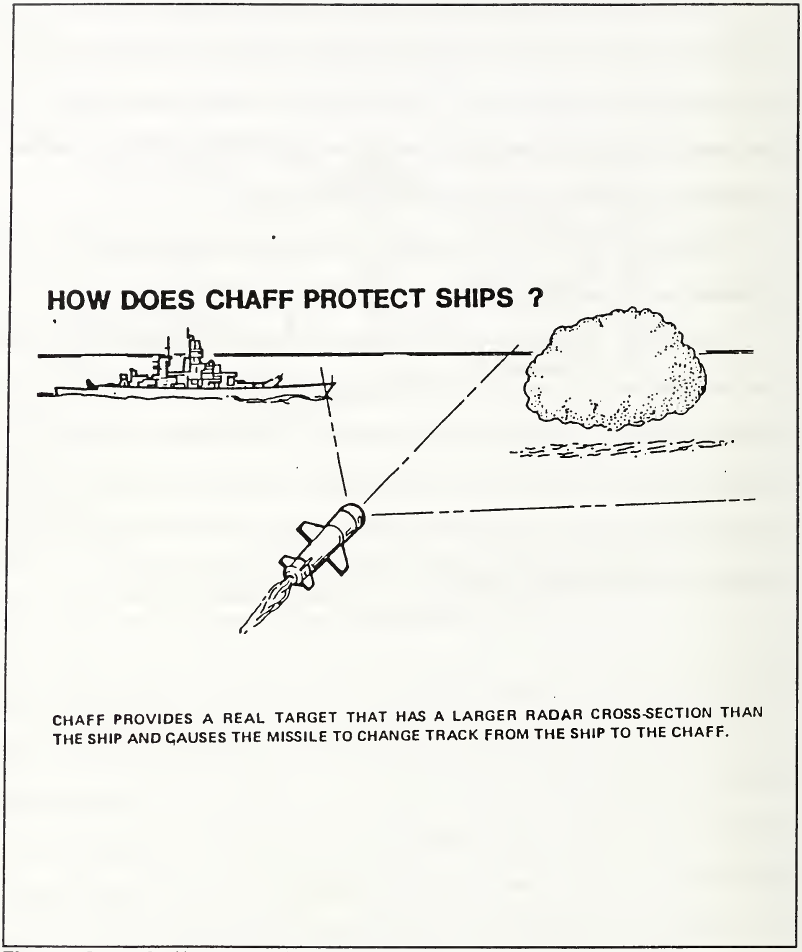


Figure 5 How chaff protects ships.(REF 11)

II. CHAFF

A. WHAT IS CHAFF

Chaff is an intentional clutter generator. It is any material/substance that can be deployed in various manners such that it introduces intentional clutter in a radar receiver. Chaff is made of wire, metal foil plastic laminates, aluminum foil and metal coated fibers and comes in the form of rope, corner reflectors, spinners, small spheres and fibers of metallized plastic cut to half wavelength to act as dipoles.

B. CHAFF CHARACTERISTICS

Chaff is characterized by several features and could be suitable or not suitable for a given task. The features to be discussed in the following sections are:

- Radar cross section
- Dispersal rate and cloud growth
- Rate of descent
- Bandwidth

In addition, the chaff should be capable of rapid deployment but that is more of a feature of the launcher than the chaff.

1. RADAR CROSS SECTION

The radar cross section of a single chaff dipole is extremely small. A chaff cloud consists of a large number of dipoles. The equations below define the radar cross section for various situations for a single chaff dipole when illuminated by a vertically polarised radar signal (REF 11).

$$\sigma = .15 * (\lambda * * 2)(\textit{FOR RANDOM ORIENTATION})$$

$$\sigma = .22 * (\lambda * * 2)(\textit{FOR HORIZONTAL ORIENTATION})$$

$$\sigma = .86 * (\lambda * * 2)(\textit{FOR VERTICAL ORIENTATION})$$

In order for chaff to be effective the radar cross section should be of the order of the carrier it is trying to protect. In our case we are trying to protect a ship and it is quite hard to characterize the RCS of a ship. Also ships have a large radar cross section that the chaff has to compete against. The ships also move at a slow speed and hence cannot carry out fast maneuvers in conjunction with the chaff deployment. The ships RCS is largest at the beam aspect and minimum when the ship is either head on or tail on. In order for a chaff cloud to be able to break lock from the ship, as in the case of the centroid mode chaff, the chaff must be inside the range gate and angle gate of the missile. The RCS of the chaff should be able to overcome the RCS of the ship. In this the important thing is that the chaff RCS is much more constant irrespective of the angle you view it from. The ship's RCS as discussed varies widely and thus it is possible for chaff with an average RCS less than the ship to be able to capture the radar gate momentarily .

The chaff areas given above are reduced further in the case when the neighboring dipoles are less than 10 wavelengths apart. By using the nomogram below, and the formula below an estimate for the RCS can be made.

$$V=2.514*(\sigma*t*d**2/\lambda*\rho)$$

where

V=volume in meters^3

σ=total RCS of chaff(meters)^2

d=diameter of dipoles(meters)

λ=wavelength of radar(meters)

ρ=chaff packing density within the chaff package

typical values ranging from .2 to .6

t= time in seconds

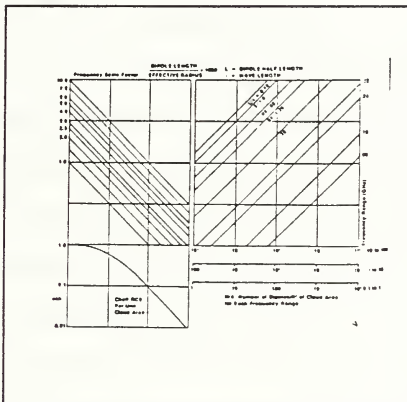
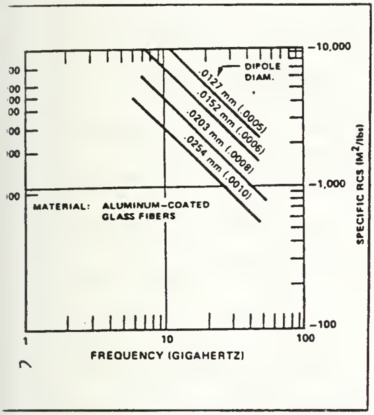


Figure 6 Shielding effects due to cloud size, dipole density can be evaluated.(REF 12)

The RCS of chaff also declines with increasing frequency. However, this effect can be countered to some extent by changing the L/d ratio as frequency increases.

For example given 123 tuned dipoles/ft^2 start at the heavy dotted line on the lower right. If the frequency is 3 Ghz the range for N is 1 to 10. A line drawn upward from 123 dipoles/ft^2 to the L/σ=.48 line indicates tuned dipoles. From this intersection, a vertical line leads down to the σ/A_c curve. Moving horizontally this value is read as .865m^2/m^2.



-e 7 RCS per dipole declines inversely increasing frequency but the effect can -untered by reducing dipole diameter -equency increases.(REF 11)

LIMITATIONS ON CHAFF RCS

- SHIELDING : This means the blocking of one chaff element by another.

- BIRDNESTING : The bunching together of the chaff elements.

- BREAKAGE : This is caused due to the wind and the forces exerted during deployment on the chaff.

C.DISPERSAL RATE

Dispersal rates are extremely important especially when dealing with fast moving platforms like the Anti-Ship Missile. For example in case of deployment of a chaff cloud in the centroid mode (where the chaff cloud is launched close to the ship so that any radar looking at the ship and the chaff cloud would see a combined echo due to both the ship and the chaff and a tracking radar would lock on to the center of the combined echo which is called the centroid) which can be done only after the missile has been detected, the total time available could be from 60 to 90 seconds. Thus, the chaff would have to be deployed within a few seconds at the most and this includes the time of travel to the location of deployment and the bloom time. The distraction chaff could, of course, take a little more time as it would be deployed all the time.

Rapid bloom dispensers can quickly disperse a large payload over a large silhouette area by dividing it into smaller packages. The diagram shows the RCS versus time for a conventional and a rapid bloom dispenser. It can be seen that the rapid bloom dispenser can fully bloom in less than 10 seconds. Modern dispensers have even smaller dispersion time.

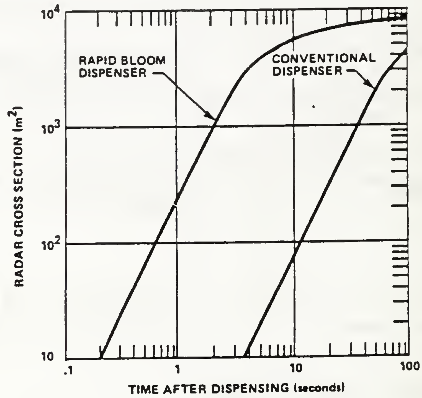


Figure 8 The rapid bloom method quickly disperses a large chaff payload over a large area by dividing it into smaller packages.(REF 5)

It is necessary that the chaff should form a viable target as soon as possible after launch, although in case of ships, the full bloom may than take a little longer.

1. RATE OF DESCENT

Since it is impossible to keep deploying chaff continuously it is essential that the chaff should have as long a persistence as possible. Thus the rate of descent becomes important. Figure 10 is a nomogram to estimate the rate of descent for various kinds of dipoles with zero wind conditions. The speed and direction of the wind can vary rapidly within several hundred feet from the ground. And this can have a profound effect on the fall rate and dispersion. Chaff fall rates can vary from one foot per second to a small fraction of a foot per second. If chaff has to be launched to decoy a sea skimming missile, the chaff can not be placed very high, and hence it will have a correspondingly small persistence as it descends to sea level from its already low altitude. If launched at 50 feet and having a descent rate of .4 feet per second then it would take about 125 seconds to come down to the sea level. This would mean that the chaff would have to be renewed every two minutes or so.

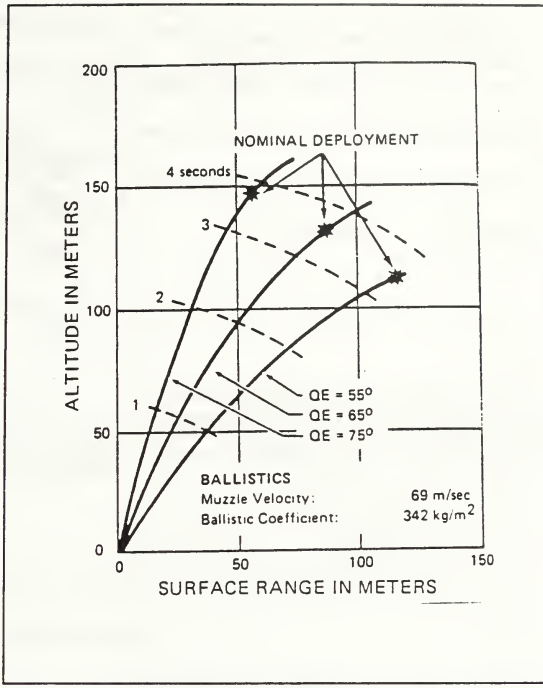


Fig 9 Chaff launched from ships has several seconds to disperse depending on altitude and range. Long dispersal times lead to alarger RCS.(REF 12).

The dipole diameter is another factor in determining the fall rate. Other factors that would effect the fall rate would be the chaff density, the aspect ratio and the geometry of the chaff fibres.

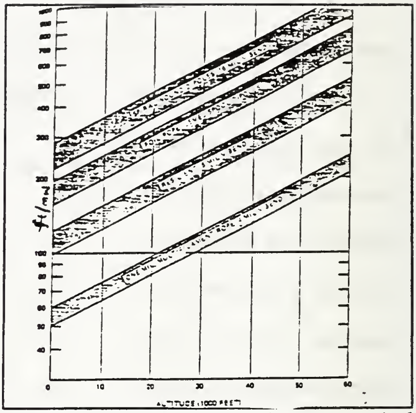


Figure 10 Descent rates in zero wind conditions.(REF 11)

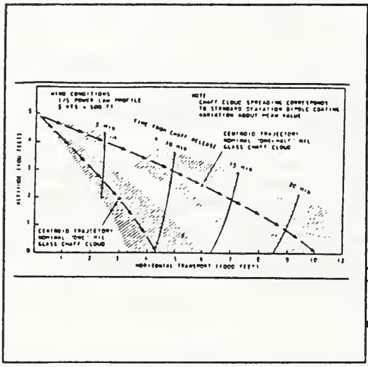


Fig 11 The effect of dipole diameter on fall rate and horizontal transport. (REF 12)

Figure 11 shows the effect of dipole diameter on the fall rate.

The horizontally oriented chaff descends slower than the vertically oriented chaff. Figure 12 shows the descent rates for horizontally oriented and vertically oriented chaff

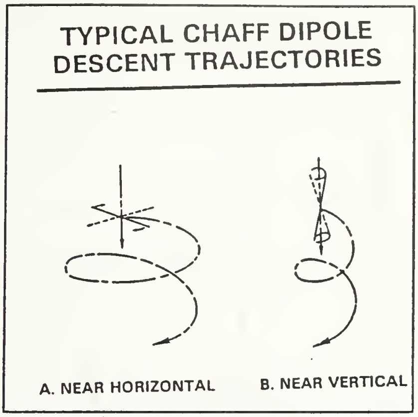


Fig 12 Horizontally oriented chaff descends slower than vertically oriented chaff. (REF 11)

2. BANDWIDTH

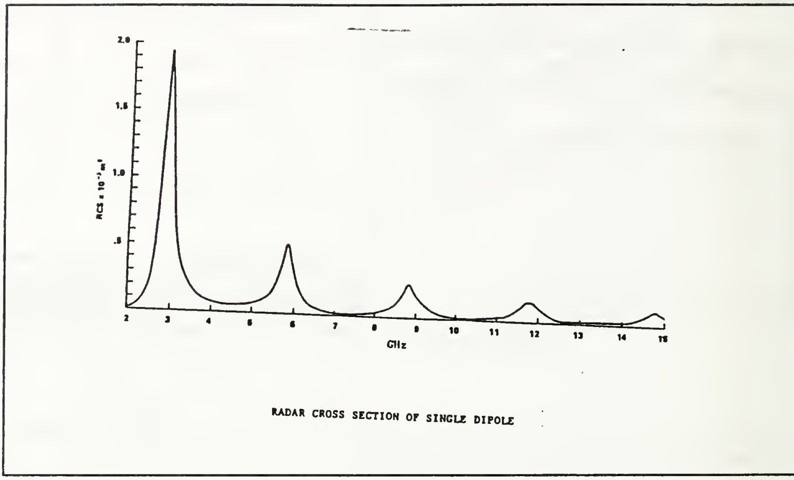


Fig 13 Change of RCS of a single dipole of chaff with change of frequency.(REF 11)

Since the exact frequency of the missile radar is usually unknown, it is necessary that the chaff have a wide bandwidth. Figure 13 shows how the RCS of a particular dipole would respond to changes in the frequency from that for which it is designed. Figure 13 shows the effect of L/d ratio on the bandwidth.

The bandwidth increases as the L/d ratio decreases. Typically the bandwidth of the chaff is of the order of 12 % to 17 %. The L/d ratio also effects the RCS if the diameter increases. The wider the bandwidth the better it is.

D. CHAFF DEPLOYMENT

There are several modes of chaff deployment. In the counter surveillance mode chaff decoys may be used to misdirect the offense so the observed location of credible targets

is different from the actual location. In this role chaff is deployed at great distances from the ship up to tens or hundreds of kilometers from the ship.

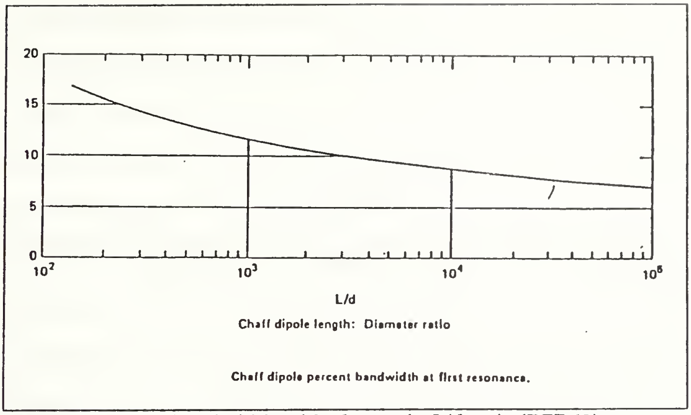


Fig 14 Change of bandwidth with change in L/d ratio.(REF 13)

In the counter targeting role (where an attempt is made to decieve the enemy as to which of the targets he sees on his radar are the ones to attack) the chaff decoy must have a credible RCS but does not have to compete with the ships RCS. The chaff must be deployed before the missile launch and is hence not so critical to launch it and deploy it rapidly.

In the counter-guidance, distraction and seduction mode the aim is to fool the missile radar. This the role envisioned in the program for the medium range chaff deployed at ranges from 1 to 2.5 NM. In the distraction mode too the chaff does not have to compete with the ship's RCS.

The differences in the various types of chaff deployed at each stage are highlighted in the Table 1 on the next page.

TABLE 1

ROLE	RCS REQD	RANGE(km)	REACTION TIME REQD
COUNTER-SURV	<SHIP	30-1000	SLOW (>1hr)
COUNTER TGTING	<SHIP	1-10	MEDIUM (<2min)
COUNTER-GUIDANCE DISTR	<SHIP	1-5	MEDIUM(<2min)
SEDUCTION	>SHIP	0-.1	FAST(<10sec)

As can be seen the distraction chaff need not be capable of rapid deployment nor need it have a RCS greater than the ship's. Thus it could be fairly inexpensive and could be continuously updated. However, the seduction chaff would have to be capable of rapid deployment and thus may be quite expensive. The diagrams below show how the track transfer takes place in seduction as the centroid shifts.

At T=1 the tracking radar sees the ship and the chaff cloud in its resolution cell and locks on to the combined echo of the two. The tracking radar now tracks the center of the combined echo. At this stage the center is on the ship. But at T=2 the center moves away from the ship's position and toward the chaff. At T=3 the ship is almost out of the resolution cell and the tracking radar is locked on to the chaff.

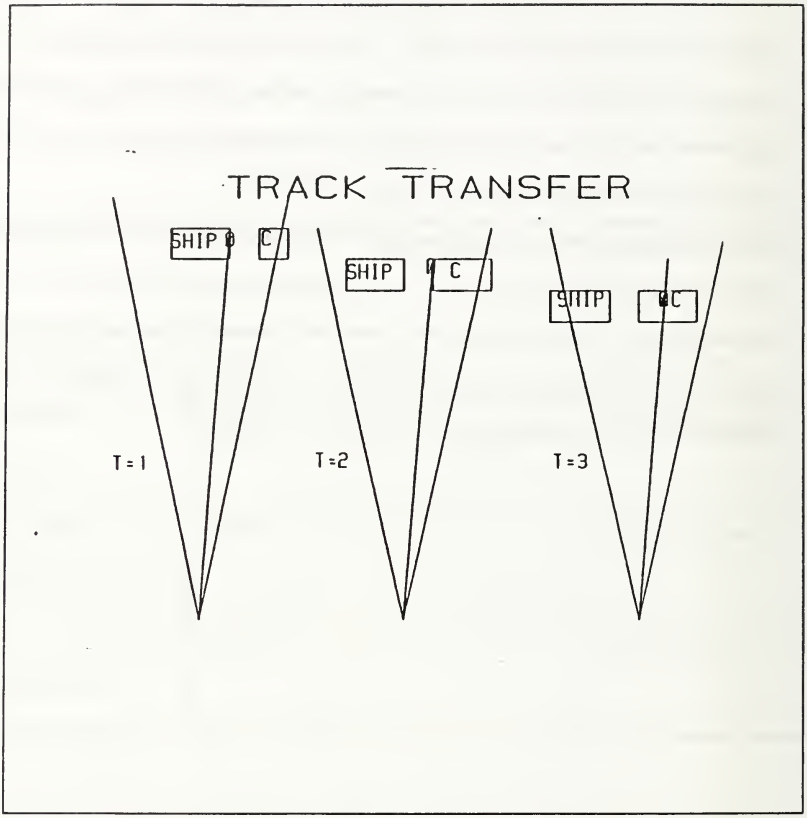


Figure 15 Track transfer from the ship to the chaff in centroid mode.(REF 11)

III. PROGRAM DESCRIPTION

A. PURPOSE

The purpose of the program is to simulate an Anti Ship Missile and to observe the effect of the launch of Medium range and Close range chaff on the Anti Ship Missile.

B. ASSUMPTIONS

The program assumes that the missile is headed for the ship when its homing head opens or at least has the ship within its arc of visibility. This means that the ship is within +/- 3 degrees of the course of the missile and the missile does not have to search for it. The medium range chaff is assumed to be launched every two minutes and can persist only for that much time. After the chaff is launched it moves at the speed of the wind which can be input.

The close range and medium range chaff are both positioned on the ship until the missile opens its homing head because they cannot effect the missile in any way until the missile opens its homing head. All bearings and courses are from North and speeds are in Knots. The parameters are entered in units as asked by the program and thereafter converted as required. The close range and medium range chaff are positioned when the missile opens its homing head by appropriately displacing them. The chaff 1 to 4 are the medium range chaff clouds and chaff 5 is the close range chaff cloud. Whereas the medium range clouds are always in position, the close range chaff is positioned only if the missile has been detected and a fixed amount of time has passed since its detection, to cater for the delay between its detection and the deployment of chaff.

C. PROGRAM STRUCTURE

The program first asks for the necessary input allowing for default values for all inputs in case they are acceptable. The logical variables are then initialized and the counters are set to the required values. The detection ranges of various sensors are calculated based on the input data.

The subroutine CONVER is then called and it converts the bearings and distances of the various chaff clouds from the missile into X and Y coordinates with the origin centered on the missile. The value of the x coordinate is saved and the program enters the main loop and stays in the main loop until the value of the x coordinate changes its sign. Until the missile opens its homing head the missile continues on the original course. The speed of the missile is always constant at 600 Knots. Once the homing head opens the missile sees the chaff rounds including the close range chaff (called chaff5) if it has been launched. The missile then carries out a search according to the search pattern decided. either far to near or near to far. The missile always looks from left to right. The missile then locks on to the target determined by its logic and steers a course for its future position. The x and y coordinates are updated every second as the program goes through the loop.

The missile also looks again after passing the first target if it has still not crossed the ship in the North South direction. If the missile locks on to the ship then until the ship has launched the chaff5 it goes for the ship but once the ship has launched the chaff5 then the missile looks at the combined echo. It calculates an equivalent target depending on the position of the ship and chaff5 with respect to the missile resolution cell center. Based on the position of the equivalent target and the direction and speed of motion of the equivalent target the missile alters course to steer for the future position of the target. For

updating the x and y coordinates of the missile with respect to the target the courses and speeds of the targets and the ship are chosen as of that second.

The ship remains on the original course and speed until it detects the missile and for a time duration of about 20 seconds thereafter, which corresponds to a relative movement between the ship and the missile of 3.5 nm. After that depending on the bearing of the missile at the time of detection the ship alters course either away or toward that bearing at the rate of 3 degrees per second.

The subroutine DMISCO selects the course to steer depending upon the positions of the chaff clouds with respect to each other and the missile. The missile locks on to the respective target and alters course to steer for the future position of the target without losing it. That is, the missile does not alter course more than 3 deg away from the target bearing. The subroutine CTS calculates the course to steer depending upon the course of the target at that instant and its speed. Thus the CTS is calculated every second. The subroutine OFFSET calculates the offset of the ship from the missile bearing depending on the course at that time and the missile bearing at that time. It is the minimum, of the difference between the missile bearing and the ship's course or the reciprocal of the ship's course and the missile bearing that is taken as the offset at that time. Note that if the ship is still maneuvering when the homing head opens, the ship's course and subsequently the offset keeps changing every second. The subroutine PARTS calculates the part of the ship inside the resolution cell depending upon the course of the missile and the offset of the ship. The chaff is assumed to have a circular dispersion and hence its area is entirely dependent upon the distance from the center of the resolution cell.

The subroutine UPDATE simply takes the x and y coordinates of the ship and the chaff clouds and the course and speed of the wind, the ship, and the equivalent target and calculates the position of the objects after every second.

The subroutine RAND is used to calculate the various random detection ranges and the random numbers required for the program.

IV PROGRAM VARIABLES

A. DEFINITIONS

1. INPUTS

- MISSCO - The course of the missile at the start of the program is input.
- CHAFCO - The wind course is the direction of movement of the chaff.
- SHPSP - The speed of the ship for the entire program.
- CHAFSP - The speed of wind for the entire program.
- SEED - The seed is either input or is calculated from the subroutine gettime.
- DUCTHT - The duct height average for the months are input as an array using averages for the month for the area of operation.
- BRGS - The bearing of the ship from the missile.
- RGES - The range of the ship from the missile at the commencement of the program is input.
- SEARCH - The search pattern is defined from near to far or from far to near.
- MO - The month of the year that we are looking at.
- HHOR - The homing head opening range.
- RGE(I) - The range of the close range and the medium range chaff from the ship at the time of start.
- TO - The throw off of the outer chaff from the ships bearing extended along the line joining the ship and the missile.
- TI - The bearing of the inner chaff from the bearing of the missile.
- HBW - The half beam width of the missile.
- SHIPCO - The course of the ship .

2. BUILT IN

- MHT - The missile height is assumed to be uniformly distributed between 9 ft and 15 ft (3 to 5 meters).

- VISDR - The visual detection range is randomly distributed between the visibility and (visibility - 5 nm).

- EWDR - The homing head opening range is assumed to be the EWDR(electronic warfare detection range is the range at which the missile is picked up by the ships ESM sensors).

- IRDR - The infra red detection range is normally distributed with a mean of 15 Nm and standard deviation of 5 NM.

- RDR - The radar detection is calculated based on the missile height and the duct height.

- DR - The detection range is the maximum of the detection ranges of various sensors.

- BRG(I) The bearing of the chaff rounds from the ship is calculated based on the throw off.

- RCSSMA - This is the ships maximum radar cross section.

- RCSSMI - This is the ships minimum radar cross section.

- RCCFMA - This is the chaff radar cross section

- DELAY - The delay between the time the medium range chaff has been launched and the time the missile opens its homing head, is uniformly distributed between 0 to 2 minutes.

- TR - The turn rate of the ship is three degrees per second.

3. CALCULATED

- MBRG - The bearing of the missile from the ship at the time the ship detects the missile.

- SHPCTS - The course for the ship to steer to offer minimum radar cross section aspect angle to the missile.

- CTS - The missile course to steer to reach the future position of the target.

- LASTX - Preserves the last x coordinate of the target.

- LASTY preserves the last y coordinate of the target.

- DXET - The difference between the x coordinate position at the time and the time just before it.

- XET - The x coordinate of the equivalent target.

- YET - The y coordinate of the equivalent target.

- XCC(I) - The distance in the x direction of chaff(i).

- YCC(I) _ The distance in the y direction of chaff(i).

- TGTNO - The target the missile locks on to.

- ETCO - The course of the equivalent target.

- ETSP - The speed of the equivalent target.

- DIFF1 & 2 - The difference between the wind direction and the bearing the chaff5 is intended to be launched. This is required for calculating the downwind direction to launch the chaff5.

- FACTC - The part of the RCS of the chaff5 in the resolution cell.

- FACTS - The part of the ship in the resolution cell.

- BRGC1 & 2 - The bearing on which to launch the chaff depending on the direction of approach of the missile.

4. LOGICALS

- HHOPEN - True when homing head is open.

- LCHCHF - True when the chaff5 has been launched.

- ENTERED - True if the missile has not opened its homing head when program starts.

- ENTER -True while the position of the chaff5 has not been determined once at the time detect becomes true.

- DETECT - True when the missile has been detected for 3.5 Nm of the missile travel.

- CHECK - True when course to steer has not been determined once.

- AGAIN - True when chaff5 has not been launched when homing head opens.

5. FUNCTIONS

- UNIFOR - The function to create uniform random variables.
- RAD - The function converts angles in degrees into radians.
- SEC - The function changes speeds in knots into nm/Sec.
- RANGE - The function changes the x y coordinates of a point to range.
- BEARG - The function changes the x y coordinates into the true bearing.
- All other variables are dummy for use with the Functions.

V. OPERETING PRINCIPLE

A. THE BEGINNING

The program starts with the missile having been launched at a range hopefully greater than the homing head opening range. The program can also start with the missile launched with homing head open. The ship being considered is capable of positioning medium range chaff at two minute intervals and on detection of the missile can if time permits launch a seduction round (close range chaff) in the time it takes the missile to travel 3.5 nm. This is also taken to be approximately the time it takes the ship to detect the missile on one of her sensors and for the report of the missile to be passed on to the command and for the command to start taking action.

B. MODELLING THE MISSILE

The missile travels at a speed of 600 knots which is approximately 600/3600 nm per second. The missile if launched in the homing head closed mode continues to proceed on the launch course until it opens its homing head. Once the missile opens its homing head it can encounter two situations.

1. SEDUCTION CHAFF NOT LAUNCHED

In this case the four medium range chaff clouds are positioned now based on the ships present position and the course and speed of the wind and the time that has elapsed between the launch of the chaff and the time the missile opens its homing head.

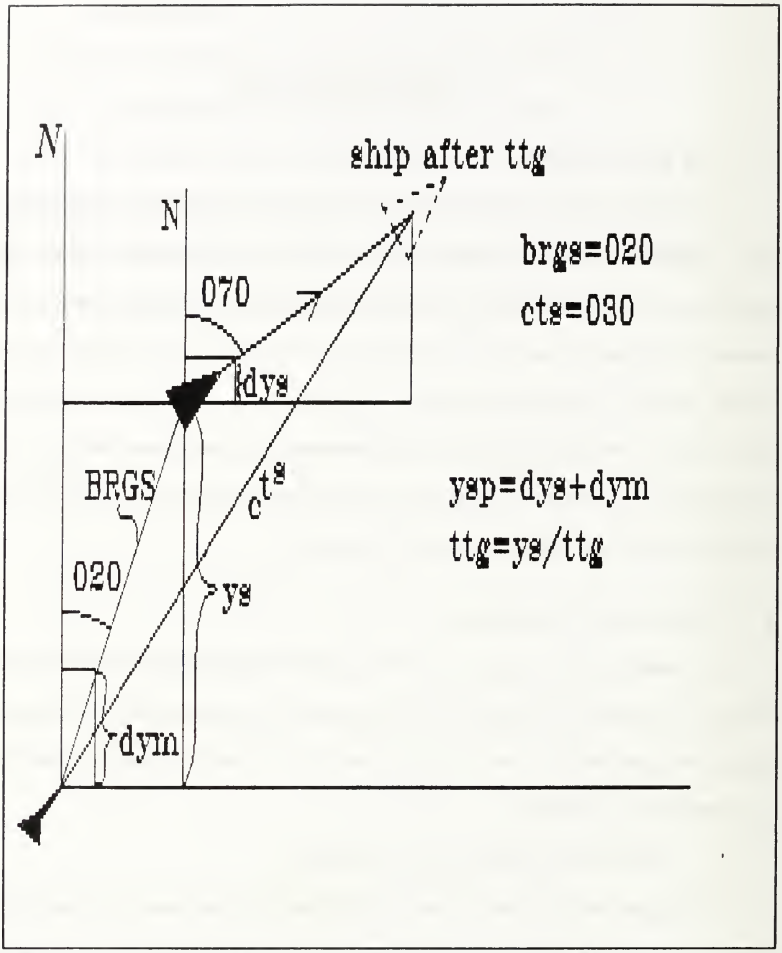


Fig 16 How the missile calculates the future position of the target.

Since the medium range chaff is renewed every two minutes the delay is modelled as a random number between zero and two minutes (0 and 120 seconds). Since the seduction chaff has not been launched its position is maintained on board the ship. The missile now looks at the available targets namely the four chaff clouds and the ship, and using the subroutine DMISCO selects a target. Then depending on the target the missile alters course for its future position. However if this course alteration is more than 3 degrees which is the half beam width of the missile the missile alters only by 3 degrees so as to avoid losing the target which it has locked on to.

The missile continues to proceed on the course for the target. The ship at this time may be maneuvering to offer minimum area of cross section. The four medium range chaff clouds are taken as point targets since they are far enough from the ship that their echoes do not combine to give one echo. Thus the missile does not look at other targets until it has crossed the target it has locked on to if the target is a medium range chaff round. In case the missile has locked on to the ship then the missile looks at the ship as a point target until it launches its seduction chaff.

2. SEDUCTION CHAFF LAUNCHED

Once the seduction chaff has been launched the missile looks at the combined echo of the ship and the medium range chaff inside its resolution cell. This depends on the area of the ship inside the resolution cell and the area of the chaff5 burst inside the resolution cell. Depending on the distance of the ship in range and bearing from the center of the missile resolution cell the part of the ship inside the resolution cell is calculated and similarly the part of the chaff inside the resolution cell is calculated. Based on the combined radar cross section the centroid of the combined echo is then calculated as the x and y coordinate of the equivalent target. The x and y coordinates are preserved in each

iteration until the next iteration and based on the x and y coordinates calculated in the next look the course and the speed of the combined echo is calculated. If the missile is locked on to this then it slowly moves away from the ship in most of the cases.

As the missile crosses the ship its x and y coordinates change sign as the coordinate system is centered on the missile. The missile position is the position at which the x coordinate is 0 and the y coordinate is 0. Therefore when the missile crosses the ship the ships x and y coordinate change sign. As this happens the missile is assumed to have crossed abeam the ship and at this time if the distance of the ship from the missile is more than 50 yards then the missile is said to have missed the ship. If the missile is within 50 yards then the missile is said to have hit the ship.

It is important to understand that the courses and positions of all contacts continue to change at all times and the response of the various subroutines which are called every second depend on the values passed at that time

C. MODELLING THE SHIP

The ship is modelled as a point target until the chaff5 round is launched. The ranges given by the sensors on the ship are given by the random numbers generated and since the seed changes every second the values are truly random if the program seed is taken. The ship continues on the course and speed it starts with until it detects the missile and for 3.5 nm of missile travel after that. Thereafter the ship is assumed to have the seduction chaff in position and commences alteration of course. The ship alters course at the rate of 3 degrees per second.

The ship alters either toward the missile bearing if the missile bearing is closer to her present course and away from the missile bearing if the reciprocal is closer to the course

she is steering at the time of detection. The ship continues to alter and steadies up on the next three degree step after it crosses the calculated course to steer.

VI. CALCULATING THE VARIABLES

- RDR - The radar detection range is calculated using the equation below

$$RDR = 1.23*(\sqrt{(DUCTHT(MO))} + \sqrt{(MHT)})$$

- SHPCTS The ship course to steer is calculated by first finding the bearing of the missile from the ship at the time of detection. Then the difference of the ship's course from the missile bearing is taken and if this is greater than 90 degrees then the ship's course to steer is the reciprocal of the missile bearing. If it is less than 90 degrees then the ship's course to steer is the mbrg.

- TR - The turn rate is negative if the ship has to turn left and positive if the ship has to turn right.

- SHIPCO - If the ship has detected the missile then if the ship has not yet reached the course to steer the ship's course keeps changing from the nearest direction until it reaches that course.

- XCC(I) = RGE(I)*SIN(BRG(I)) for i=1,4

- YCC(I) = RGE(I)*COS(BRG(I)) for i=1,4

- XC(I) = XS + XCC(I) + DELAY*60 *SIN(CHAFCO) for i=1,4

- YC(I) = YS + YCC(I) + DELAY*60* SIN(CHAFCO) for i=1,4

- TGTCO =CHAFCO if the target is one of the chaff clouds or the ship course if the target is the ship.

- TGTSP =CHAFSP if the target is one of the chaff clouds or the SHIPSP if the ship is the target.

- ETCO & ETSP - The ship's course and the ship's speed are the ETCO and ETSP until the seduction chaff is launched. After that the ETCO & ETSP are calculated. The previous x and y coordinates are stored in LASTX & LASTY and then the next time around the ETCO & ETSP are calculated using the shift between the two coordinates that is DXET and DYET. Then the ETCO & ETSP are calculated as follows-

  ETSP =sqrt(DXET**2+DYET**2)
  ETCO = ATAN2 (DXET,DYET)

- BRG(5) - The bearing of the chaff5 is calculated based on the bearing of the missile. The intent is to launch the chaff5 perpendicular to the direction of the incoming missile so that the throw off is the maximum. But to select one of the two perpendicular directions the wind direction is used. The chaff5 is launched in the direction in which it will be carried away from the ship by the wind. This is done using the difference DIFF1 and DIFF2 between the wind direction and the chaffs two intended directions and the chaff is launched in the direction in which the difference is the minimum.

- RGE(5) - The range at which to launch the chaff5 is determined by using the missile distance at the time of launch and the HBW of the missile. The chaff5 is launched at the maximum distance at which it will still be within the resolution cell of the missile. This is calculated using the equation-

  RGE(5)=RGES*HBW

- OFFSET - The offset of the ship or its reciprocal is calculated using the ships bearing from the missile and its course and taking the minimum of the two angles that is angle between the ships bearing and its course and the ships course reciprocal and the bearing of the missile.

- XC(5) & YC(5) - This is calculated using the equation given below

  XC(5)=XS+XCC(5)+COUNTER*CHAFSP*SIN(CHAFCO)
  YC(5)=YS+YCC(5)+COUNTER*CHAFSP*COS(CHAFCO)

- where XCC(5) & YCC(5) are calculated as for the other 4 chaffs using BRG(5) and RGE(5). The COUNTER keeps track of the number of iterations that have taken place since the CHAFF5 has been placed. This is to give it the necessary displacement. This method of placing the chaff is done only once. Thereafter the chaff moves at the course and speed of the wind as the other chaffs do.

- XTGT & YTGT - Are the x and y coordinates of the target selected.

- FACTS & FACTC - These represent the area of the ship and the chaff5 that is inside the chaffs resolution cell of the missile. If the center of the object is within 1 degree of the missile resolution cell center then the object is assumed to be completely inside the resolution cell in bearing. Similarly if the object center is within 10 yds in range from the missile resolution cell center then the part inside the resolution cell is full. If the object is fully inside the resolution cell in both bearing and range then its FACTS or FACTC as the case may be is one. As the object center moves away from the resolution cell center in both range and bearing or either of the two its FACTS or FACTC as the case may be reduces correspondingly until it is fully outside the resolution cell when the FACTS OR FACTC go to zero. The part of the ship and the chaff cloud burst inside the resolution cell is calculated in the subroutine PARTS and then by multiplying the part inside in range and in bearing the FACTS and FACTC are obtained as the proportion of both the ship and the chaff inside the resolution cell.

$$RCSC=FACTC*RCCFMA$$

$$RCSS=FACTS*((RCSSMA-RCSSMI)*SIN(OFFSET)+RCSSMI)$$

- RCSS & RCSC - The radar cross section of the ship and the chaff inside the resolution cell are calculated using the equation 7 and 8.

- XET & YET- In case the chaff5 is launched the XET & YET are calculated as follows

$$YET=(YS*RCSS+YC(5)*RCSC)/(RCSS+RCSC)$$

- $$XET=(XS*RCSS+XC(5)*RCSC)/(RCSS+RCSC)$$

CTS - The course to steer for the missile is calculated using the distance in the y direction and the total speed in the y direction. The time to go TTG is then calculated by dividing the distance by the speed. This is then used to calculate where the target will be after that much time. The missile course to steer is then the course for this future position. This will change if the ship continues to alter course and is updated every second.

- DR - The detection range is the maximum detection range of any of the sensors and is calculated by first calculating the detection ranges of the various sensors and then taking the maximum of these as the detection range.

VIII. POSSIBLE MODIFICATIONS TO THE PROGRAM

It is possible to change the program in some ways to achieve different types of results. The program can be changed to have the medium range chaff deployed at shorter or longer intervals as necessary. Also the various parameters that have been assumed for the ship or the missile could be changed to suit specific needs of a specific ship. Some ships for example could have much larger RCS and some ships have a much smaller RCS. Similarly the chaff could have a different RCS. Another factor that could be taken into account is the chaff cloud growth and decay with time.

Another place where some changes could be made to the program would be to the turn rates of the ship. Also the program does not consider the vertical field of view of the missile and hence any contact in its resolution cell in bearing is assumed to be fully inside the missile's seeker cell. But if the chaff were to be too high this would not be true.

The program assumes the ranges of detection of the various sensors to be distributed according to some distribution but if something more of the detection were to be known these could be accordingly modified. An example would be the visual detection range of the missile. This is hard to estimate due to the fact that the human element is involved. Also the duct hights here are averages.

If the actual duct height were to be known the duct height could be included in the program to give the actual range of detection of the radar. Also not much is known about the detection range of the IRST systems. The French system VAMPIR is advertised to have a detection range for an ASM to be 10 KM. However it is not certain if the actual range is much more or less.

The program could be made to produce a graphical output at the end of each run to give the actual performance of the missile. The program could be made to coordinate the launch of SAM and guns and close in weapon systems.

IX PROGRAM ANALYSES

The number of variables in the anti ship missile defence problem make it difficult to draw firm conclusions about a particular situation. The real value of the program is in using it for situations in which the relevant data about detection ranges is known and the data about the missiles various parameters can be predicted with reasonable accuracy. The information about the wind data is also very important. In most regions of the world the winds move as per a given pattern for long periods of the year and the speeds vary according to the time of the day and other factors. Thus for a given duration it would be possible to make predictions about the possibility of the ship being hit by a particular type of missile and the responsible factors could be removed.

In the 300 trial runs conducted, nine hits on the ship were obtained by the missile for the given range of medium range chaff and throw off of the medium range chaff and the given mode of deployment of the close range chaff. This amounts to a 97 percent success rate for the chaff. Of these some of the hits were technical hits in that the missile was locked on to the equivalent target (the center of the combined echo of the close range chaff and the ship but passed close to the ship. But these should be taken as hits as in some cases (three to be precise) the missile locked on to the ship but the program did not give a hit as the range of the missile was greater than 50 yards from the ship as the missile locked on to the ship only at the last stage.

The trials were carried out at different courses of the wind in 15 degree steps. The ships course was changed for each course of the wind through 360 degrees in 45 degree steps. The trials were carried in one 180 degrees sector from 225 degrees to 045 degrees.

The missile's course was maintained at 090 degrees as this would not make a difference to the result as all aspect angles of the ship and wind course were tried out. For each of the wind's courses and for each of the ship's courses 3 different trials were carried out at different wind speeds which were varied from 3 Knots to 12 Knots.

There were almost no hits on the ship when the wind course was from 315 to 225. This is 45 degrees on either side of the missile course direction. Basically this is due to the fact that the chaff does not move on to the ship. Of course if the wind speed were known the position for launching the chaff could be calculated and thus a missile hit could be avoided. But given the fact that the time available to respond to a missile is going to be always very short an automatic response would be desirable. Thus given the wind conditions and other factors such as likely detection range the chaff deployment could be changed based on the trials of the program. The hits on the ship occurred when the wind course and direction was just right to push the chaff on to the ship.

Further trials of the program would be useful if the detection range and the homing head opening range of the missile could be predicted and the wind and ships course were known. But that is always going to be a variable and thus a scheme would need to be developed that will give the best probability of decoying the missile given the known factors. In the absence of better knowledge of the various parameters the program could be a useful tool for the deployment of the medium range and close range chaff.

APPENDIX A

```
*   MAIN PROGRAM THIS IS THE PART WHERE ALL THE SUBROUTINES ARE
*   CALLED AND VARIOUS VARIABLES ARE DECLARED AND DEFINED.ALL
*   INPUTS  ARE OBTAINED HERE AND THE VARIOUS RANDOM VALUES USED
*   IN THE PROGRAMME ARE DEFINED HERE.THE PROGRAMME BASICALLY
*   CONSIDERS THREE SITUATIONS.  1)THE PEOGRAMME  STARTS WITH HH
*   CLOSE AND THE MISSILE NOT DETECTED.2)THE PROGRAMME STARTS WITH
*   HOMING  HEAD  OPEN BUT THE CLOSE RGE CHAF NOT YET
*   LAUNCHED.3)THE HOMING HEAD IS OPEN AND THE CHAF IS ALSO
*   LAUNCHED.THE LONG RANGE CHAF IS  POSITIONED AFTER THE HH IS OPEN
*   ONLY AND IS DISPLACED FOR MOVEMENT  RANDOMLY DISTRIBUTED FROM
*   0 TO 2 MIN.
     real mht,missco,shipco,chafco,missp,shipsp,
    +ductht(12),hhor,rge(5),brg(5),dr,shpcts,dxet,dyet,
    +xs,ys,xc(5),yc(5),brgs,rges,to,ti,rad,sec,vx,xv,
    +chafsp,rec,tu,tv,s,xet,yet,offset,bearg,range,diff1,diff2,
    +rcssma,mbrg,rccfma,rcssmi,factc,facts,brgc1,brgc2,xtgt,ytgt,
    +xcoor,ycoor,delay,xcc(5),ycc(5),etco,etsp,lastx,lasty

     integer search,mo,count,h/0/,counter,tgtno,case,j
     integer*2,ihr,isec,imin,i100th
```

```
 double precision zi,unifor,rand,pi,rdr,irdr,tr,
+visdr,vis,a,b,z,c,d,x

 common pi,zi
 character*25 line$,blank$/'                         '/
 character*20 lock(8)
 logical crschf,hhopen,lchchf,enter,detect,entered,again,check,
+stop1,stop2,stop3
 range(xcoor,ycoor)=sqrt(xcoor**2+ycoor**2)
 bearg(xcoo,ycoo)=atan2(xcoo,ycoo)

 unifor(a,b,z)= a+(b-a)*rand(z)
 rad(xv)=xv*.01745329252  !CONVERTS DEGREES INTO RADIANS.
 sec(vx)=vx/3600.0      !CONVERTS SPEED IN KNOTS INTO MILES/SEC
 pi=3.141592654d0
 rcssma=10000.0
 rcssmi=4500.0
 rccfma=10000.0

 data lock/'chaf1','chaf2','chaf3','chaf4','chaf5','ship','eqtgt',
+'none'/

*

 ductht(1)=34.0   !
```

```
      ducht(2)=45.0    !
      ducht(3)=40.0    !
      ducht(4)=36.0    !
      ducht(5)=55.0    !
      ducht(6)=60.0    !
      ducht(7)=52.0    ! THESE ARE THE DUCTS HIGHTS FOR THE DIFFFERENT
      ducht(8)=50.0    ! MONTHS.
      ducht(9)=43.0    !
      ducht(10)=40.0  !
      ducht(11)=40.0  !
      ducht(12)=36.0  !
*     DATA ENTRY START!
*
      call gettim(ihr,imin,isec,i100th)
      zi=i100th*10000+isec*100+imin
    1 write(*,'(" seed=",f15.0)')zi
      write(*,'(" enter new seed or zero for keeping this seed")')
      print*,'to stop enter a negative seed'
      read*,a
      if (a.ne.0.d0)zi=a
      if(a.lt.0.0) stop
*
      print*,'enter ship course in degrees from 0 to 360 deg or press'
      print*,'enter for default course 120'
```

```
read(*,'(A)') line$
if(line$.eq.blank$)then
   shipco=120
else
   read(line$,'(f10.0)')shipco
endif
print*,'shipco=',shipco
shipco=rad(shipco)
if(shipco.gt.pi) shipco=shipco-2*pi !convert to fortran course

*
print*,'enter ship speed in  knots or press enter for default'
print*,'speed ie 15 knots'
read(*,'(A)') line$
if(line$.eq.blank$)then
   shipsp=15.0
else
   read(line$,'(f10.0)')shipsp
endif
print*,'shipsp=',shipsp
shipsp=sec(shipsp)
*
print*,'enter wind speed in knots or press enter for default '
print*,'value 5 knots'
```

```
read(*,'(A)') line$
if(line$.eq.blank$) then
   chafsp=5.0
else
    read(line$,'(f10.0)')chafsp
endif
print*,'chafsp=',chafsp
chafsp=sec(chafsp)
*
print*,'enter wind course in degrees from 0 to 360 deg or press'
print*,'enter for default course 045'
read(*,'(A)') line$
if(line$.eq.blank$)then
   chafco=045
else
   read(line$,'(f10.0)')chafco
endif
print*,'chafco=',chafco

chafco=rad(chafco)
if(chafco.gt.pi) chafco=chafco-2*pi
*

print*,'enter missile course in deg eg 160 or press enter for'
```

```
 print*,'default value 090 deg'
 read(*,'(A)')line$
 if(line$.eq.blank$)then
   missco=090
 else
   read(line$,'(f10.0)')missco
 endif
 print*,'missco=',missco
 missco=rad(missco)
 if(missco.gt.pi) missco=missco-2*pi
 misssp=600
 misssp=sec(misssp)
*
 print*,'enter ship range in  NM or press enter for default'
 print*,'range ie 20 NM'
 read(*,'(A)') line$
 if(line$.eq.blank$)then
   rges=20.0
 else
   read(line$,'(f10.0)')rges
 endif

 print*,'rges=',rges
```

```
print*,'enter throw off of inner chaff from the missile bearing'
print*,'or press enter for default 10 deg'
read(*,'(A)')line$
if (line$.eq.blank$)then
  tu=10
else
  read(line$,'(f10.0)')tu
endif
print*,'tu=',tu
ti=rad(tu)
*

print*,'enter throw off of outer chaff from the missile bearing'
print*,'or press enter for default 45 deg'
read(*,'(A)')line$
if (line$.eq.blank$)then
  tv=45
else
  read(line$,'(f10.0)')tv
endif
print*,'tv=',tv
```

```
 to=rad(tv)
*

 print*,'enter range of inner chaff  in NM or press enter'
 print*,' for default range ie 1.5 NM'

 read(*,'(A)') rge(1)
 if(line$.eq.blank$)then
   rge(1)=1.5
 else
   read(line$,'(f10.0)')rge(1)
 endif
 print*,'rge(1)=',rge(1)
 rge(2)=rge(1)

 print*,'enter range of outer chaff  in NM or press enter'
 print*,'for default range ie 1.1 NM'
 read(*,'(A)')line$
 if(line$.eq.blank$)then
   rge(3)=1.1
 else
   read(line$,'(f10.0)')rge(3)
 endif
 print*,'rge(3)=',rge(3)
```

```
rge(4)=rge(3)
hbw=3
hbw=rad(hbw)
print*,'enter search type or press enter for search type 1'
read(*,'(A)')line$
if(line$.eq.blank$)then
   search=1
else
   read(line$,'(i10)')search
endif

n=4
rec=missco+pi
if(rec.gt.pi) rec =rec-2*pi
brgs=missco

mht=unifor(9,15,zi)
print*,'enter homing head opening range  NM or press enter'
print*,' for default range ie 10 NM'
read(*,'(A)')line$
if(line$.eq.blank$)then
   hhor=10.0
else
   read(line$,'(f10.0)')hhor
```

```
endif
print*,'hhor  =',hhor
print*,'enter month of the year or press enter for default month'
print*,'month May'
read(*,'(A)')line$
if(line$.eq.blank$)then
   mo=5
else
   read(line$,'(f10.0)')mo
endif
print*,'mo =',mo

print*,'enter visibility    in  NM or press enter'
print*,' for default visibility ie 12 NM'
read(*,'(A)')line$
if(line$.eq.blank$)then
   vis =12.0
else
   read(line$,'(f10.0)') vis
endif
print*,' vis  =', vis
crschf=.false.
brg(3)=missco-to
brg(4)=missco+to
```

```
      brg(1)=rec+ti
      brg(2)=rec-ti
*     DATA ENTRY END


***************     START OF THE PROGRAMME ******************************
*   IN THIS PART DETECTION RANGES OF VARIOUS SENSORS ARE CAALCULATED
*    DEPENDING ON THE VAIOUS INPUTS AND THERANDOM NUMBER
*    GENERATORS


************************** DETECTION RANGES *************************
      visdr=unifor(vis-5.0d+00,vis,zi) !UNIFORMLY DISTRIBUTED
      c=rand(zi)
      d=rand(zi)
      x=((-2*dlog(c))**.5)*(dcos(2*pi*d))
      irdr=15+x*5 ! THE INFRARED DET RANGE IS NORMAL WITH MEAN 15 AND
*     print*,irdr ! STANDARD DEV 5 NM
      rdr=1.23*(sqrt(ductht(mo))+sqrt(mht))!RDR EQN USING MHT AND DUCTHT
      ewdr=hhor ! THE MISSILE IS DETECTED BY EW WHEN HOMING HEAD OPENS
      dr=amax1(rdr,irdr,visdr,ewdr)!DET OCCURS AT MAX RGE OF ALL SENSORS
      print*,'detection range is'
      print*,dr


********************END DETECTION RANGES CALCULATION******************
```

```
******************** INITIALISATION OF LOGICALS ************************

      call conver(rges,brgs,rge,brg,xc,yc,xs,ys)
      print*,xc(1),yc(1)
      open (unit=40,file='udate',status='unknown')
      write(40,'("   run with shipco='',f8.3)')shipco*180/pi
      write(40,'("   chaffco='',f8.3)')chafco*180/pi
      write(40,'("   chaffsp='',f8.3)')chafsp*3600

      write(40,'("   brgc1   brgc2   brgc3   brgc4   brgc5   brgs    br
     +et  missco   cou        '')')
      s=xs
      enter=.true.
      entered=.false.
      count=0
      counter=0
      delay=unifor(0,2,zi)       !DELAY BETWEEN MEDIUM RGE CHAF LAUNCH
*     print*,'delay=',delay      !AND HOMING HEAD OPENING.
      check=.true.
      again=.true.
      stop1=.true.
      stop2=.true.
      stop3=.true.
      j=1
      tr=0.0
```

```
****************** MAIN LOOP STARTS ********************************

 67  if (s*xs.gt.0.0) then

       count=count+1          !KEEPS TRACK OF NUMBER OF ITERATIONS.

       if(range(xs,ys).le.(50.0/2025.0))then

          go to 68

       endif

       if (range(xs,ys).gt.hhor) then

          hhopen=.false.

       else

          hhopen=.true.

          dowhile(stop1)

             print*,'homing head is open'

             stop1=.false.

          enddo

       end if

       if(range(xs,ys).gt.(dr-3.5)) then

          lchchf=.false.

       else

          lchchf=.true.

       end if

       if(range(xs,ys).gt.(dr-3.5)) then

          detect=.false.
```

```
      else
        detect=.true.
      end if
      if (detect) then  !IF DETECTION HAS OCCURED DETERMINE CTS
        counter=counter+1 ! KEEP TRACK OF ITERATIONS AFTER DETECTION
*     THE STEPS INSIDE THE DO LOOP ARE PERFORMED ONCE AT THE TIME OF
*     DETECTION TO DETERMINE THE BEARING TO LAUNCH THE CENTROID
*     CHAFF.
        dowhile(check)
          print*,'Detection has occured'
          brgs=atan2(xs,ys)
          if(brgs.gt.pi) brgs =brgs-2*pi
          mbrg=brgs+pi
          if(mbrg.gt.pi) mbrg =mbrg-2*pi
          if(shipco.gt.pi) shipco =shipco-2*pi
          if((abs(shipco-mbrg)).le.(pi/2))then
            shpcts=mbrg
          else
            shpcts=mbrg+pi
            if(shpcts.gt.pi)shpcts=shpcts-2*pi
          endif
          print*,'missile brg=',mbrg*57.295,'shpcts=',shpcts*57.295
          if(((shpcts.ge.0).and.(shpcts.lt.pi)).and.
     +    ((shipco.ge.0).and.(shipco.lt.pi)))then
```

```
      case=1
      if(shpcts.ge.shipco)then
        tr=3*pi/180
      else
        tr=-3*pi/180
      endif
    elseif(((shpcts.lt.0).and.(shpcts.gt.-pi)).and.
+   ((shipco.lt.0).and.(mbrg.gt.-pi)))then
      case=1
      if(shpcts.ge.shipco)then
        tr=3*pi/180
      else
        tr=-3*pi/180
      endif
    else
      case=2
      if(((shpcts.gt.0).and.(shpcts.le.pi/2)).or.
+     ((shpcts.gt.-pi).and.(shpcts.le.-pi/2)))then
        tr=3*pi/180
      else
        tr=-3*pi/180
      endif
    endif
    if(shipco.gt.pi) shipco =shipco-2*pi
```

```
          if(shipco.lt.-pi) shipco=shipco+2*pi
          print*,'turn rate=',tr

          check=.false.  !TO ENSURE THAT CTS IS NOT CALCULATED AGAIN
        enddo
      endif
*     THESE STEPS ARE TO KEEP CHANGING THE SHIPS COURSE  AFTER
*     AFTER  DETECTION OCCURS UNTIL THE SHIP CROSSES THE CTS AND THEN
*     STEADY UP.
*     THE TURN RATE TR IS 3 DEG PER SECOND.
      if((case.eq.1).or.((shpcts.gt.-pi/2).and.
   +  (shpcts.lt.pi/2)))then

        if(tr.lt.0.0)then
          if(shipco.gt.shpcts) then
            shipco=shipco+tr
          else
            shipco=shipco
          endif
        elseif(tr.gt.0.0)then
          if(shipco.lt.shpcts)then
            shipco=shipco+tr
          else
            shipco=shipco
```

```
        endif
      endif
    else
      if(tr.lt.0.0)then
        if(shipco.gt.(shpcts-2*pi)) then
          shipco=shipco+tr
        else
           shipco=shipco
        endif
      elseif(tr.gt.0.0)then
        if(shipco.lt.(shpcts+2*pi))then
          shipco=shipco+tr
        else
          shipco=shipco
        endif
      endif
    endif


*    THERE ARE TWO SITUATIONS NOW 1) THE HOMING HEAD IS NOT OPEN 2)
*   HOMING HEAD OPEN.  IF HH IS NOT OPEN THEN THE MISSILE JUST GOES ON
*    LAUNCH COURSE IRRESPECTIVE OF CHAFF5  BEING LAUNCHED OR NOT.

    if (.not.hhopen) then  !homcls
```

```
      entered=.true.
      xet=xs
      yet=ys
      do    33 i=1,5
        xc(i)=xs
        yc(i)=ys
        etco=shipco
        etsp=shipsp

33    continue
      if(count.eq.j*10)then
        print*,'missco=',missco*180/pi
        j=j+1
      endif
      call update(missco,missp,shipco,shipsp,chafco,chafsp,xs,
     +      ys,xc,yc,hhopen)



      go to 67
*   IF THE HOMIG HEAD IS OPEN THEN THE MISSILE LOOKS TO LOCK ON TO A
*   TARGET AND STEERS THE COURSE FOR IT.  IF CHAF5 IS NOT LAUNCHED
*   THEN THE  EQUIVALENT TARGET IS THE SAME AS THE SHIP BUT THE OTHER
*   4 CHAFS IE 1 TO 4 ARE NOW PUT INTO POSITION DEPENDING ON THE DELAY.
```

```
      else     !IF HOMING HEAD IS OPEN
*    HOMING HEAD IS OPEN BUT CHAF5 NOT YET LAUNCHED.

        if (.not.lchchf) then
          xc(5)=xs
          yc(5)=ys
          xet=xs
          yet=ys
          do while (again) !POSITION THE 4 CHAFS ONCE .
              do 11 i=1,4
                xcc(i)=rge(i)*sin(brg(i))
                ycc(i)=rge(i)*cos(brg(i))
                xc(i)=xs+xcc(i)+delay*60*sin(chafco)*chafsp
                yc(i)=ys+ycc(i)+delay*60*cos(chafco)*chafsp
                print*,'after calc with hh open ch5 not lch'
                print*,xc(i),yc(i)
11            continue
            print*,'Missile head opened chaf5 not launched'
            again=.false.  ! THE STEPS IN LOOP ARE DONE ONCE ONLY.
          print*,'inside loop 2'
          end do
          etco=shipco
          etsp=shipsp
```

```
      call   dmisco (missco,xs,ys,xc,yc,
     +              hbw,search,xet,yet,tgtno)
      if((tgtno.ge.1).and.(tgtno.le.5))then
        tgtco=chafco
        tgtsp=chafsp
        if(tgtno.eq.1)then
          xtgt=xc(1)
          ytgt=yc(1)
          lock='chaf1'
        elseif(tgtno.eq.2)then
          xtgt=xc(2)
          ytgt=yc(2)
          lock='chaf2'
        elseif(tgtno.eq.3)then
          xtgt=xc(3)
          ytgt=yc(3)
          lock='chaf3'
        elseif(tgtno.eq.4)then
          xtgt=xc(4)
          ytgt=yc(4)
          lock='chaf4'
        elseif(tgtno.eq.5)then
          xtgt=xc(5)
          ytgt=yc(5)
```

```
    lock='chaf5'
  endif



elseif(tgtno.eq.0)then
  tgtco=shipco
  tgtsp=shipsp
  lock='ship'
  xtgt=xs
  ytgt=ys
elseif(tgtno.eq.6)then
  xtgt=xet
  ytgt=yet
  lock='eqtgt'
  tgtco=etco
  tgtsp=etsp
elseif(tgtno.eq.10)then
  tgtco=shipco
  tgtsp=shipsp
  lock='none'
  print*,'prigramme stopped'
  go to 68
endif
if(count.eq.j*10) then
```

```
  print*,'tgtco=',tgtco*180/pi,'tgtsp=',tgtsp*3600
  j=j+1
 endif
 call miscts(tgtco,tgtsp,missco,misssp,xtgt,ytgt,cts)

 if(abs(missco-cts).lt.rad(hbw))then
   missco=cts
 else
   if((missco-cts).lt.0.0)then
      missco=missco+rad(hbw)
   else
      missco=missco-rad(hbw)
   endif
 endif

 if(count.eq.j*10)then
   write(40,15)bearg(xc(1),yc(1))*180/pi,
+  bearg(xc(2),yc(2))*180/pi,
+  bearg(xc(3),yc(3))*180/pi,
+  bearg(xc(4),yc(4))*180/pi,
+  bearg(xc(5),yc(5))*180/pi,
+  brgs*180/pi,
+  bearg(xet,yet)*180/pi,
+  missco*180/pi,
```

```
+          count
           write(40,'("locked on to  ",A)')lock
           print*,'missile steering',missco

           print*,'brgc1=',bearg(xc(1),yc(1))*180/pi
           print*,'brgc2=',bearg(xc(2),yc(2))*180/pi
           print*,'brgc3=',bearg(xc(3),yc(3))*180/pi
           print*,'brgc4=',bearg(xc(4),yc(4))*180/pi
           print*,'brgc5=',bearg(xc(5),yc(5))*180/pi
           print*,'brgs=',brgs*180/pi
           print*,'bearing eq tgt= ',bearg(xet,yet)*180/pi
           print*,'missco=',missco*180/pi
           print*,'xet=',xet,'  yet=',yet
           print*,'count=',count
         endif
         call update(missco,missp,shipco,shipsp,chafco,
+                     chafsp,xs,ys,xc,yc,hhopen)
         go to 67
       else     !CHAFF LAUNCHED AND HOMING HEAD OPENED

         do while(enter)! STEPS TO DETERMINE CHAF5 POSITION ONCE
           brgs=bearg(xs,ys)
           print*,'brgs on opening homing head =',brgs
           rges=range(xs,ys)
```

```
*     THE BRG & RGE OF CHAF5 AND THE 4 OTHER CHAF IS FOUND

      brgc1=brgs+pi/2
      brgc2=brgs-pi/2
      if(brgc1.gt.pi)brgc1=brgc1-2*pi
      if(brgc2.lt.-pi)brgc2=brgc2+2*pi
      diff1=abs(chafco-brgc1)
      diff2=abs(chafco-brgc2)
      if(diff1.gt.pi)diff1=2*pi-diff1
      if(diff2.gt.pi)diff2=2*pi-diff2
      if(diff1.lt.diff2)then
        if(ewdr.lt.(dr-3.5))then
          brg(5)=brgc2
        else
          brg(5)=brgc1
        endif
      else
        if(ewdr.lt.(dr-3.5)) then
          brg(5)=brgc1
        else
          brg(5)=brgc2
        endif
      endif
      rge(5)=rges*.33333*hbw
```

```
      print*,'brg(5)=',brg(5)
      h=h+1
      if ((again).and.(entered)) then
        open(unit=9,file='result',status='unknown')
        do 12 i=1,4
          xcc(i)=rge(i)*sin(brg(i))
          ycc(i)=rge(i)*cos(brg(i))
          xc(i)=xs+xcc(i)+delay*chafsp*60*sin(chafco)
          yc(i)=ys+ycc(i)+delay*chafsp*60*cos(chafco)
12      continue

        xcc(5)=rge(5)*sin(brg(5))
        ycc(5)=rge(5)*cos(brg(5))
        xc(5)=xs+xcc(5)+counter*chafsp*sin(chafco)
        yc(5)=ys+ycc(5)+counter*chafsp*cos(chafco)

        xet=(xs+xc(5))/2
        yet=(ys+yc(5))/2
      else

        xcc(5)=rge(5)*sin(brg(5))
        ycc(5)=rge(5)*cos(brg(5))
        xc(5)=xs+xcc(5)+counter*chafsp*sin(chafco)
        yc(5)=ys+ycc(5)+counter*chafsp*cos(chafco)
```

```
        xet=(xs+xc(5))/2
        yet=(ys+yc(5))/2

      endif

      do 13 i=1,5
        print*,'brg chaf',i,'=',bearg(xc(i),yc(i))*180/pi
        print*,'range chaf',i,'=',range(xc(i),yc(i))
        print*,'missco=',missco
        print*,'bearing ship=',brgs
13    continue
      enter=.false.
    end do

    call offst(shipco,xs,ys,offset)
    if(count.eq.j*10)then
      print*,'count=',count
      print*,'shipcourse=',shipco
      print*,'offset=',offset

    endif
    call  dmisco (missco,xs,ys,xc,yc,
 +        hbw,search,xet,yet,tgtno)
```

```
if((tgtno.ge.1).and.(tgtno.le.5))then
 tgtco=chafco
 tgtsp=chafsp
 if(tgtno.eq.1)then
   xtgt=xc(1)
   ytgt=yc(1)
   lock='chaf1'
 elseif(tgtno.eq.2)then
   xtgt=xc(2)
   ytgt=yc(2)
   lock='chaf2'
 elseif(tgtno.eq.3)then
   xtgt=xc(3)
   ytgt=yc(3)
   lock='chaf3'
 elseif(tgtno.eq.4)then
   xtgt=xc(4)
   ytgt=yc(4)
   lock='chaf4'
 elseif(tgtno.eq.5)then
   xtgt=xc(5)
   ytgt=yc(5)
   lock='chaf5'
 endif
```

```
 elseif(tgtno.eq.0)then
   tgtco=shipco
   tgtsp=shipsp
   lock='ship'
   xtgt=xs
   ytgt=ys
 elseif(tgtno.eq.6)then
   xtgt=xet
   ytgt=yet
   lock='eqtgt'
   tgtco=etco
   tgtsp=.01
 elseif(tgtno.eq.10)then
    tgtco=shipco
    tgtsp=shipsp
    lock='none'
    print*,'program stopped'
    go to 68
 endif
 if(count.eq.j*10)then
   print*,'count=',count
   print*,'tgtco=',tgtco*180/pi,'tgtsp=',tgtsp*3600
 endif
```

```
      call parts(xs,ys,xc,yc,xtgt,ytgt,facts,factc)
      rcsc=factc*rccfma
      rcss= facts*((rcssma-rcssmi)*sin(offset)+rcssmi)
      if(count.eq.j*10)then
        print*,'chaf area=',rcsc,'   ship area=',rcss
        print*,'facts=',facts,'FACTC=',factc
      endif
      lastx=xet
      lasty=yet
      xet=(xs*rcss+xc(5)*rcsc)/(rcss+rcsc)
      yet=(ys*rcss+yc(5)*rcsc)/(rcss+rcsc)
      if(count.eq.j*10)then
*       open (unit=40,file='udate',status='unknown')
        write(40,15)bearg(xc(1),yc(1))*180/pi,
     +  bearg(xc(2),yc(2))*180/pi,
     +  bearg(xc(3),yc(3))*180/pi,
     +  bearg(xc(4),yc(4))*180/pi,
     +  bearg(xc(5),yc(5))*180/pi,
     +  brgs*180/pi,
     +  bearg(xet,yet)*180/pi,
     +  missco*180/pi,
     +  count
 15     format(8(1x,f7.2),1x,i4)
        write(40,'("locked on to ",A)')lock
```

```
      print*,'brgc1=',bearg(xc(1),yc(1))*180/pi
      print*,'brgc2=',bearg(xc(2),yc(2))*180/pi
      print*,'brgc3=',bearg(xc(3),yc(3))*180/pi
      print*,'brgc4=',bearg(xc(4),yc(4))*180/pi
      print*,'brgc5=',bearg(xc(5),yc(5))*180/pi
      print*,'bearing eq tgt= ',bearg(xet,yet)*180/pi

      print*,'brgs=',brgs*180/pi
      print*,'missco=',missco*180/pi
      print*,'xet=',xet,'   yet=',yet
      j=j+1
    endif
    dxet=xet-lastx
    dyet=yet-lasty
    etsp=.01
    etco=atan2(dxet,dyet)


    call miscts(tgtco,tgtsp,missco,misssp,xtgt,ytgt,cts)
*   if(abs(missco-cts).lt.rad(hbw))then
      missco=cts
*   else
*     if((missco-cts).lt.0.0)then
*        missco=missco+rad(hbw)
```

```
*             else
*                missco=missco-rad(hbw)
*             endif
*           endif
            print*,'missile steering',missco*180/pi
            call update(missco,misssp,shipco,shipsp,chafco,chafsp,
     +      xs, ys,xc,yc,hhopen)

            go to 67

         endif
      endif
    else
      print*,'count=', count
    end if

68  if(range(xs,ys).le.(50.0/2025.0))then
      print*,'count=',count
      print*,'the ship was hit'
      print*,'bearing of ship was    ', bearg(xs,ys)*180/pi
      print*,'the range was   ',range(xs,ys)
    else
      print*,'count=',count
      print*,'the ship is safe'
```

```
    print*,'bearing of ship was    ', bearg(xs,ys)*180/pi
    print*,'the range was   ',range(xs,ys)
    print*,'s=',s,' xs=',xs,' ys=',ys
  endif
  go to 1
  end
```

```
  Subroutine update(missco,missp,shipco,shipsp,chafco,chafsp,xs,
 +      ys,xc,yc,hhopen)

*  THIS SUBROUTINE TAKES THE COURSES AND SPEEDS OF THE SHIP, THE WIND
*   AND THE MISSILE FROM THE MAIN PROGRAM AND CALCULATES
*   DEPENDING ON THESE AND THE POSITION OF THE CHAF AND THE SHIP
*   AND THE EQUIVALENT   TARGET DETERMINES THE POSITION OF THE CHAF
*   AND THE SHIP WRT THE MISSILE IN TERMS OF THE X & Y COORDINATES
*   AFTER CONSIDERING THE  MOVEMENT IN THE LAST SECOND.
  Real missco,missp,shipco,shipsp,chafco,chafsp,xc(5),
```

```
+      yc(5),xs,ys,dmy,dmx,dsx,dsy,dcx,dcy

       integer i
       common/seed/zi,pi
       logical hhopen
       double precision pi
       if (hhopen) then

         dmx=misssp*sin(missco)
         dmy=misssp*cos(missco)
         dsx=shipsp*sin(shipco)
         dsy=shipsp*cos(shipco)
         dcx=chafsp*sin(chafco)
         dcy=chafsp*cos(chafco)

*        detx=etsp*sin(etco)
*        dety=etsp*cos(etco)
*        xet=xet-dmx+detx
*        yet=yet-dmy+dety

         xs=xs-dmx+dsx
         ys=ys-dmy+dsy
         do  30 i=1,5
            xc(i)=xc(i)-dmx+dcx
```

```
       yc(i)=yc(i)-dmy+dcy
 30   continue
     else
       dmx=misssp*sin(missco)
       dmy=misssp*cos(missco)
       dsx=shipsp*sin(shipco)
       dsy=shipsp*cos(shipco)
       xs=xs-dmx+dsx
       ys=ys-dmy+dsy
     endif
     return
     end


     Subroutine conver(rges,brgs,rge,brg,xc,yc,xs,ys)
*    THIS SUBROUTINE IS USED TO DETERMINE THE X & Y COORDINATES OF THE
*     CHAF 1 TO 4 AND THE X & Y COORDINATES OF THE SHIP DEPENDING ON
*      THE  BEARING AND RANGE OF THE CHAF FROM THE SHIP.

     real brg(4),rge(4),brgc(4),xs,ys,xcc(4),ycc(4),xc(4),yc(4),
    +brgs,rges,rgec(4),xcoor,ycoor,xcoo,ycoo,bearg,
    +range
     integer i
```

```
      double precision pi
      range(xcoor,ycoor)=sqrt(xcoor**2+ycoor**2)
      bearg(xcoo,ycoo)=atan2(xcoo,ycoo)

      pi=4.0d+00*datan(1.0d+00)

      xs=rges*sin(brgs)
      ys=rges*cos(brgs)
      do 10 i=1,4
        xcc(i)=rge(i)*sin(brg(i))
        ycc(i)=rge(i)*cos(brg(i))
        xc(i)=xs+xcc(i)
        yc(i)=ys+ycc(i)
        rgec(i)=range(xc(i),yc(i))
        brgc(i)=bearg(xc(i),yc(i))*180/pi
 10   continue
      return
      end

      Subroutine dmisco (missco,xs,ys,xc,yc,
     + hbw,search,xet,yet,tgtno)
*
```

```
*    THIS SUBROUTINE IS USED TO DETERMINE THE TARGET TO LOCK ON TO
*    AND  IF NONE OF THE TARGETS IS WITHIN THE MISSILE HOMING HEAD
*    THEN TO  KEEP THE COURSE SAME AS BEFORE.  FIRST THE TARGETS ARE
*    CHECKED IN  BEARING AND THEN THE RANGE IS ALSO CHECKED.  IF THE
*    TARGETS ARE IN THE LOOK AREA OF THE MISSILE THE MISSILE LOCKS  ON
*    TO THE TARGET.

      real missco,xc(4),yc(4),xcoor,ycoor,xcoo,ycoo,
     +hbw,p,q,r,s,t,u,v,brgc1,brgc2,brgc3,brgc4,select,
     +brgs,xs,ys,xet,yet,brget,brgc5,bearg,range
      integer search,tgtno
      double precision pi
      logical s1,c1,c2,c3,c4,c5,et
      range(xcoor,ycoor)=sqrt(xcoor**2+ycoor**2)
      bearg(xcoo,ycoo)=atan2(xcoo,ycoo)


      s1=.false.
      c1=.false.
      c2=.false.
      c3=.false.
      c4=.false.
      c5=.false.
      et=.false.
```

```
 pi=4.0d+00*datan(1.0d+00)
 if(missco.gt.pi)missco=missco-2*pi
 if(missco.lt.-pi)missco=missco+2*pi

 p=range(xs,ys)
 q=range(xc(1),yc(1))
 r=range(xc(2),yc(2))
 s=range(xc(3),yc(3))
 t=range(xc(4),yc(4))
 u=range(xc(5),yc(5))
 v=range(xet,yet)
 brgc1=bearg(xc(1),yc(1))
 brgc3=bearg(xc(3),yc(3))
 brgc2=bearg(xc(2),yc(2))
 brgc4=bearg(xc(4),yc(4))
 brgs=bearg(xs,ys)
 brgc5=bearg(xc(5),yc(5))
 brget=bearg(xet,yet)

 if((brgs.ge.(missco-hbw)).and.(brgs.le.
+      (missco+hbw))) then
   s1=.true.
 endif
```

```
if(.not.s1)then
   if(search.eq.1)then
      p=1000.0
   else
      p=0.0
   endif
endif



if ((brgc1.ge.(missco-hbw)).and.(brgc1
+        .le.(missco+hbw))) then
   c1=.true.
endif
if(.not.c1)then
   if(search.eq.1)then
      q=1000.0
   else
      q=0.0
   endif
endif



if((brgc2.ge.(missco-hbw)).and.(brgc2
+        .le.(missco+hbw))) then
```

```
  c2=.true.
endif
if(.not.c2)then
  if(search.eq.1)then
    r=1000.0
  else
    r=0.0
  endif
endif


if((brgc3.ge.(missco-hbw)).and.(brgc3
+      .le.(missco+hbw))) then
  c3=.true.
endif
if(.not.c3)then
  if(search.eq.1)then
    s=1000.0
  else
    s=0.0
  endif
endif
```

```
 if((brgc4.ge.(missco-hbw)).and.(brgc4
+        .le.(missco+hbw))) then
    c4=.true.
 endif
 if(.not.c4)then
    if(search.eq.1)then
       t=1000.0
    else
       t=0.0
    endif
 endif


 if((brgc5.ge.(missco-hbw)).and.(brgc5
+        .le.(missco+hbw))) then
    c5=.true.
 endif
 if(.not.c5)then
    if(search.eq.1)then
       u=1000.0
    else
       u=0.0
    endif
 endif
```

```
if (search.eq.1) then
   select=amin1(p,q,r,s,t,u,v)
else
   select=amax1(p,q,r,s,t,u,v)
endif

if (select.le.15) then

   if((select.eq.q).and.((brgc1.ge.(missco-hbw)).and.(brgc1
+        .le.(missco+hbw)))) then
      missco=brgc1
      print*,'locked on to chaf1'
      tgtno=1
   elseif((select.eq.r).and.((brgc2.ge.(missco-hbw)).and.(brgc2
+        .le.(missco+hbw)))) then
      missco=brgc2
      print*,'locked on to chaf2'
      tgtno=2
   elseif((select.eq.s).and.((brgc3.ge.(missco-hbw)).and.(brgc3
+        .le.(missco+hbw)))) then
      missco=brgc3
      print*,'locked on to chaf3'
```

```
      tgtno=3
     elseif((select.eq.t).and.((brgc4.ge.(missco-hbw)).and.(brgc4
     +     .le.(missco+hbw)))) then
      missco=brgc4
      print*,'locked on to chaf4'
      tgtno=4
     elseif((c5.and.s1).and.(xs.ne.xet)) then


      missco=brget
      print*,'locked on to et'
      tgtno=6
     elseif((select.eq.u).and.((brgc5.ge.(missco-hbw)).and.(brgc5
     +     .le.(missco+hbw)))) then
      missco=brgc5
      tgtno=5
      print*,'locked on to chaf5'
     elseif(( select.eq.p).and.((brgs.ge.(missco-hbw)).and.(brgs.le.
     +     (missco+hbw)))) then
      missco=brgs
      print*,'locked on to the ship'
      tgtno=0


     else
      print*,'not locked on to anyone'
```

```
      tgtno=10
    endif
  else
    print*,'nobody within range'
  endif
  return
  end


  subroutine miscts(shipco,shipsp,missco,misssp,xet,yet,cts)
*
*  HERE THE MISSILE STARTS TO STEER FOR THE FUTURE POSITION OF THE
*  TARGET THAT IT IS LOCKED ON TO.IF THE MISSILE IS LOCKED ON TO ONE
*  OF THE CHAFS THEN IT DETERMINES  THE FUTURE POS OF THE CHAF AND
*  IF LOCKED ON TO THE SHIP OR THE CENTROID THEN IT STEERS FOR THE
*  FUTURE POSITION OF THE SHIP OR THE EQUIVALENT TARGET.

  real shipco,shipsp,missco,misssp,ttg,ysp,dxs,dys,xlt,ylt,cts,
 +xet,yet
  ysp=abs(shipsp*cos(shipco)+misssp*cos(missco))
  ttg=abs(yet/ysp)
*  print*,'time to go=',ttg/10.0
  dxs=ttg*shipsp*sin(shipco)
  dys=ttg*shipsp*cos(shipco)
```

```
xlt=xet+dxs
ylt=yet+dys
cts=atan2(xlt,ylt)
return
end



subroutine offst(shipco,xs,ys,offset)
*
*  THE OFFSET IS THE ANGLE OF THE SHIPCO OR THE RECIPROCAL FROM THE
*  MISSILE BEARING .  IF THE MISSILE IS HEADED FOR THE SHIP AND THE
*  SHIP IS HEADED FOR  THE MISSILE THIS ANGLE IS 0.ELSE IT CAN BE
*  ANYWHERE FROM 0 TO 90 DEGREES.
*


real shipco,sipco,xs,ys,offset,mbrg,brgs
double precision pi
brgs=atan2(xs,ys)
pi=3.141592654d0
mbrg=brgs+pi
sipco=shipco
if(mbrg.gt.pi)mbrg=mbrg-2*pi
```

```
if(mbrg.lt.-pi)mbrg=mbrg+2*pi
if(sipco.lt.-pi)sipco=sipco+2*pi
if(sipco.gt.pi)sipco=sipco-2*pi
offset=abs(sipco-mbrg)
if(offset.gt.pi/2)offset=abs(offset-pi)
if(offset.gt.pi/2)offset=abs(offset-pi/2)
return

end




subroutine parts(xs,ys,xc,yc,xet,yet,facts,factc)
*
*  THIS SUBROUTINE CALCULATES THE PART OF THE SHIP AND THE CLOSE RGE
*   CHAF INSIDE THE RESOLUTION CELL OF THE MISSILE.IF THE MISSILE IS
*   LOCKED ON TO THE CENTROID THEN THE MISSILE RESOLUTION IS ON THE
*   X & Y COORDINATES OF THE EQUIVALENT TARGET.
*



real  xs,ys,xc(5),yc(5),xet,yet,facts,factc,xds,yds,
+factc1,factc2,facts1,facts2,brget,brgs,brgc,rges,rgec,rge
double precision pi
```

```
pi=3.141592654d0

xds=xet-xs
yds=yet-ys
rge=sqrt(xet**2+yet**2)
rges=sqrt(xs**2+ys**2)
rgec=sqrt(xc(5)**2+yc(5)**2)
brgs=atan2(xs,ys)
brgc=atan2(xc(5),yc(5))
print*,'xet=',xet,'yet=',yet
brget=atan2(xet,yet)
if((abs(brgc-brget)).le.(pi/180))then
   factc1=1
elseif((abs(brgc-brget)).le.(2*pi/180))then
   factc1=.75
elseif((abs(brgc-brget)).le.(3*pi/180))then
   factc1=.5
elseif((abs(brgc-brget)).le.(3.5*pi/180))then
   factc1=.25
else
   factc1=0.01
endif
if((abs(brgs-brget)).le.(pi/180))then
   facts1=1
```

```
elseif((abs(brgs-brget)).le.(2*pi/180))then
   facts1=.75
elseif((abs(brgs-brget)).le.(3*pi/180))then
   facts1=.5
elseif((abs(brgs-brget)).le.(3.5*pi/180))then
   facts1=.25
else
   facts1=0.01
endif

if((abs(rgec-rge)).le.(10.0/2025.0)) then
   factc2=1
elseif((abs(rgec-rge)).le.(30.0/2025.0)) then
   factc2=.75
elseif((abs(rgec-rge)).le.(50.0/2025.0)) then
   factc2=.5
elseif((abs(rgec-rge)).le.(80.0/2025.0)) then
   factc2=.25
else
   factc2=0.01
endif

*     print*,'rges=',rges,'rge=',rge,'rgec=',rgec
if((abs(rges-rge)).le.(10.0/2025.0)) then
```

```
   facts2=1
elseif((abs(rges-rge)).le.(30.0/2025.0)) then
   factc2=.75
elseif((abs(rges-rge)).le.(50.0/2025.0)) then
   facts2=.5
elseif((abs(rges-rge)).le.(80.0/2025.0)) then
   facts2=.25
else
   facts2=0.01
endif
facts=facts1*facts2
factc=factc1*factc2
return
end


double precision function rand(p)
double precision p,b,c
data b/2147483647.d0/,c/2147483648.d0/
p=dmod(16807.d0*p,c)
rand=p/b
return
end
```

APPENDIX B

This section contains the results of the trials conducted. Three trials were carried out for each of the ship's courses. The ship's course was varied through 360 degrees for each course of the wind. The wind course changed from 045 to 225 degrees(a 180 deg sector). The first column contains the ranges obtained for each run. Three detection ranges are given for each ships course because three trials were conducted for each course. The ranges were different due to the changing seed which is automatically calculated by the program based on the time at that instant. The third column is divided into three to show the targets the missile locked on to in each of the runs. The fourth column gives the result of each of the runs. The trials were conducted with a fixed throw off and distance of the medium range chaff. The close range chaff was deployed by the program in a predetermined position depending on the missile range and bearing.

LEGEND 1,2,3,4,5 MEANS CHAFF 1 OR 2 OR 3 ETC
ET MEANS EQUIVALENT TARGET
SHIP MEANS THE 'SHIP'
N MEANS THE MISSILE IS NOT LOCKED ON TO ANYTHING
S MEANS SAFE IN THE REMARKS COLUMN AND SHIP IN THE TARGETS COLUMN AND HIT MEANS THE SHIP HAS BEEN HIT

CHAFF COURSE 045 DEG
SHIP SPEED 15 KNOTS
SEED RANDOM

DETECTION RANGE OF MISSILE	SHIP COURSE	TARGETS LOCKED ON TO			STATUS/REMARKS		
17.3/15.4/13.1	005	2/5	2/ET	2/N	S	HIT	S
14.5/16.3/17.2	045	2/N	2/ET	2/N	S	S	S
12.7/19.1/14.2	090	2/N	2/ET	2/1/N	S	HIT	S
14.3/17.6/13.5	135	1/N	1/N	1/N	S	S	S
15.1/17.8/16.2	180	1/N	1/N	1/N	S	S	S
16.2/13.5/17.9	225	1/N	1/N	1/N	S	S	S
19.3/13.4/23.8	270	2/N	2/1/N	2/ET/5	S	S	S
21.3/13.2/16.9	315	2/N	2/ET/5	2/N	S	S	S

CHAFF COURSE 030

DETECTION RANGE OF MISSILE	SHIP COURSE	TARGETS LOCKED ON TO			STATUS/REMARKS		
17.6/18.5/25.7	005	2/ET/5	2/N	2/N	S	S	S
22.6/16.5/15.9	045	2/1/N	2/N	2/ET/N	S	S	S
17.1/27.4/14.9	090	2/N	2/N	2/5/N	S	S	S
15.3/18.7/24.3	135	1/N	1/N	1/N	S	S	S
22.7/17.4/18.3	180	1/N	1/N	1/N	S	S	S
14.2/27.1/13.1	225	1/N	1/N	1/N	S	S	S
12.1/15.1/18.7	270	2/N	2/1/N	2/N	S	S	S
15.3/12.4/23.4	315	2/5/N	1/N	1/N	S	S	S

CHAFF COURSE 015 DEG

DETECTION RANGE OF MISSILE	SHIP COURSE	TARGETS LOCKED ON TO			STATUS/REMARKS		
16.3/18.3/25.6	005	2/N	2/N	2/N	S	S	S
17.2/19.5/22.8	045	2/N	2/ET/N	2/N	S	S	S
26.1/15.2/17.6	090	2/5/N	2/5/N	2/N	S	S	S
12.1/15.2/18.4	135	2/5/ ET/S	1/N	1/N	HIT	S	S
15.6/17.2/18.3	180	1/N	1/N	1/N	S	S	S
17.2/26.1/17.3	225	1/N	1/N	1/N	S	S	S
22.3/13.2/18.4	270	1/N	2/1/N	2/N	S	S	S
12.5/16.2/13.4	315	2/N	2/N	2/N	S	S	S

CHAFF COURSE 000

DETECTION RANGE OF MISSILE	SHIP COURSE	TARGETS LOCKED ON TO			STATUS/REMARKS		
17.2/19.1/13.2	005	1/S	1/ET/S	2/S	S	HIT	S
14.1/15.0/16.3	045	2/S	2/N	2/S	S	S	S
16.2/18.1/23.6	090	2/5/N	2/5/ ET/N	2/N	S	S	S
17.1/12.3/17.4	135	1/N	2/N	1/N	S	S	S
13.2/18.5/16.1	180	2/N	1/N	1/N	S	S	S
12.4/27.2/16.5	225	1/N	1/N	1/N	S	S	S
15.5/16.2/20.9	270	2/N	2/N	2/S	S	S	HIT
14.5/16.2/19.1	315	2/N	2/N	2/ET/5	S	S	S

CHAFF COURSE 345

DETECTION RANGE OF MISSILE	SHIP COURSE	TARGETS LOCKED ON TO			STATUS/REMARKS		
15.1/16.4/13.1	005	2/N	2/N	2/N	S	S	S
22.3/19.1/12.3	045	2/N	2/N	2/N	S	S	S
13.5/13.2/13.6	090	2/N	2/N	2/N	S	S	S
17.5/13.1/15.3	135	1/N	1/N	1/N	S	S	S
18.1/13.6/21.8	180	1/N	1/N	1/N	S	S	S
13.8/14.8/13.1	225	1/N	1/N	1/N	S	S	S
12.9/13.6/15.2	270	2/N	2/5/N	2/N	S	S	S
19.7/16.4/15.4	315	2/N	2/N	2/N	S	S	S

CHAFF COURSE 330

DETECTION RANGE OF MISSILE	SHIP COURSE	TARGETS LOCKED ON TO			STATUS/REMARKS		
13.2/16.4/13.0	05	2/5/N	2/N	2/S	S	S	HIT
13.1/16.7/21.9	45	2/S	2/N	2/N	HIT	S	S
18.6/17.1/16.8	90	2/ET/5 /N	2/N	2/ET/5/ N	S	S	S
16.1/18.1/13.2	135	1/N	2/ET/N	1/N	S	S	S
17.3/12.9/19.8	180	1/N	1/N	1/N	S	S	S
16.0/13.0/18.2	225	1/N	1/N	1/N	S	S	S
21.0/24.1/17.6	270	2/N	2/5/ ET/S	2/N	S	HIT	S
26.6/14.7/13.0	315	2/N	2/S/ ET/N	2/N	S	S	S

CHAFF COURSE 315

DETECTION RANGE OF MISSILE	SHIP COURSE	TARGETS LOCKED ON TO			STATUS/REMARKS		
13.8/17.1/13.7	005	2/S/N	2/N	2/ET/5	S	S	S
19.5/21.7/13.4	045	1/N	2/N	2/S	S	S	S
19.2/13.4/18.8	090	2/ET/N	2/N	2/N	S	S	S
13.4/13.0/20.4	135	1/N	1/N	2/ET/N	S	S	S
12.8/23.1/13.4	180	1/N	2/N	1/N	S	S	S
20.6/15.7/13.7	225	1/N	2/ET/5 /N	1/S	S	S	HIT
14.1/21.8/15.2	270	ET/N	2/N	2/N	S	S	S
14.5/13.5/17.9	315	2/5/N	2/ET/5 /N	2/S/ HIT	S	S	HIT

CHAFF COURSE 300

DETECTION RANGE OF MISSILE	SHIP COURSE	TARGETS LOCKED ON TO			STATUS/REMARKS		
15.7/16.9/17.1	005	2/ET/5	2/ET/5 /N	2/ET/5/ N	S	S	S
20.3/13.8/13.7	045	2/N	2/ET/5 /N	2/5	S	S	S
18.4/13.1/13.8	090	2/N	2/N	2/N	S	S	S
20.5/19.1/15.0	135	1/N	1/N	1/N	S	S	S
20.1/17.7/13.4	180	1/N	1/N	1/N	S	S	S
18.6/12.9/19.0	225	1/N	1/N	1/N	S	S	S
13.6/16.4/15.6	270	2/N	2/5/N	2/ET/5/ N	S	S	S
13.7/12.9/19.2	315	2/ET/5 /N	2/1/N	2/N	S	S	S

CHAFF COURSE 275

DETECTION RANGE OF MISSILE	SHIP COURSE	TARGETS LOCKED ON TO			STATUS/REMARKS		
18.5/13.3/13.3	005	2/N	2/N	2/N	S	S	S
13.8/14.0/21.7	045	2/N	2/N	2/N	S	S	S
16.4/17.8/17.3	090	2/N	2/N	2/N	S	S	S
13.8/13.5/13.6	135	1/N	1/N	1/N	S	S	S
18.0/13.5/15.0	180	1/N	1/N	1/N	S	S	S
25.1/19.7/20.4	225	1/N	1/N	1/N	S	S	S
13.4/20.6/13.7	270	2/N	2/N	2/N	S	S	S
13.4/20.3/22.6	315	2/N	2/N	2/N	S	S	S

CHAFF COURSE 250

DETECTION RANGE OF MISSILE	SHIP COURSE	TARGETS LOCKED ON TO			STATUS/REMARKS		
19.1/13.2/13.2	005	2/N	2/N	2/N	S	S	S
13.9/16.6/23.4	045	2/N	2/N	2/N	S	S	S
13.7/16.9/13.0	090	1/N	1/N	1/N	S	S	S
22.7/13.1/21.4	135	1/N	1/N	1/N	S	S	S
12.8/14.0/13.2	180	1/N	1/N	1/N	S	S	S
15.3/17.1/14.1	225	1/5/N	1/N	1/5	S	S	S
13.5/13.0/13.5	270	1/N	1/N	1/5	S	S	S
13.2/13.1/12.9	315	2/5/N	2/N	2/N	S	S	S

CHAFF COURSE 225

DETECTION RANGE OF MISSILE	SHIP COURSE	TARGETS LOCKED ON TO			STATUS/REMARKS		
16.4/13.0/15.5	005	2/N	2/N	2/N	S	S	S
13.5/18.9/12.9	045	2/N	1/N	2/N	S	S	S
18.8/19.9/13.1	090	2/N	1/N	1/N	S	S	S
13.2/13.2/16.4	135	1/N	2/N	2/N	S	S	S
15.0/20.3/13.8	180	1/ET/5 /N	1/N	1/5/N	S	S	S
13.5/21.6/17.6	225	1/N	1/N	1/ET/5	S	S	S
13.2/15.3/13.7	270	1/N	1/ET/5	1/5	S	S	S
14.7/29.1/14.3	315	1/ET/5	1/N	2/N	S	S	S

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